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THESIS

SPATIAL MODELING FOR SUSTAINABLE COASTAL ZONE MANAGEMENT

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy(Sustainable Land Use and Natural Resource Management)
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Siriluk Prukpitikul 2015: Spatial Modeling for Sustainable Coastal Zone Management. Doctor of Philosophy (Sustainable Land Use and Natural Resources Management), Major Field: Sustainable Land Use and Natural Resources Management, Interdisciplinary Graduate Program. Thesis Advisor: Assistant Professor Payattipol Narangajavana, Ph.D. 204 pages.

This study focuses on the long-term coastal zone change over the past 15 years at Hat Chao Samram, Petchaburi province, Thailand. The appraisal of cause and effect on coastal zone change was performed by spatial detection, long-term monitoring, assessment, modeling, and prediction. Temporal data consists of satellite images during 1999-2012, oceanographic and meteorological data, socio-economic data from a field survey and questionnaire. Overall data were rearranged for spatial format analysis.

The results found that the coastal zone change related to natural and man-made factors depending on the monsoon period. Critical erosion and accretion was 1.38 (km^2) (2009–2010) and 1.49 (km^2) (2004-2005), respectively. The relationship between erosion and land use type was statistically significant with aquaculture, urban and building areas, bare land and agriculture areas (P-value > 0.1). Long-term spatial modeling provided the erosion high risk areas (0.49 km^2) in the middle part and the estuaries southern part, medium risk area (1.3 km^2) with a distance of 50-100 m, and the low risk areas (0.9 km^2) after 100 m from the shoreline. The total economic vulnerability of 182.8 million baht was threatened by coastal erosion.

This long-term spatial modeling which is the automatic geo-processing tool including physical, social and economic aspects has beneficial to improve the monitoring, analysis and prediction for the similar coastal zone pattern management under the sustainability concept.

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Siriluk Prukpitikul
May, 2015

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LIST OF ABBREVIATIONS

m	- Meter
m/s	- Meter/second
cm/s	- Centimeter/second
Jan	- January
Feb	- February
Mar	- March
Apr	- April
May	- May
Jun	- June
Jul	- Jul
Aug	- August
Sep	- September
Oct	- October
Nov	- November
Dec	- December
E	- Easterly winds
NE	- Northeasterly winds
SE	- Southeasterly winds
W	- Westerly winds
N	- Northerly winds
S	- Southerly winds
SW	- Southwesterly winds
NW	- Northwesterly winds
Km^2	- Square kilometer
m^2	- Square meter
m/yr	- Meter/year

GLOSSARY

Coastal accretion	-	The process of coastal sediment returning to the visible portion of a beach or foreshore following a submersion event. A sustainable beach or foreshore often goes through a cycle of submersion during rough weather then accretion during calmer periods. If a coastline is not in a healthy sustainable state, then erosion can be more serious and accretion does not fully restore the original volume of the visible beach or foreshore leading to permanent beach loss. (http://en.wikipedia.org/wiki/Accretion_(coastal_management)
Coastal erosion	-	The process of wearing away material from a coastal profile due to imbalance in the supply and export of material from a certain section. It takes place in the form of scouring in the foot of the cliffs or dunes or at the subtidal foreshore. Coastal erosion takes place mainly during strong winds, high waves and high tides and storm surge conditions, and results in coastline retreat and loss of land (Mangor, 2004)
Coastal Sensitivity Index	-	The factors that are sensitive and relevant to the changing of coastal areas (Boruff et al., 2005).
Coastal zone change	-	A natural phenomenon, which has always existed and has the wearing a way of land and the removal of beach or dune. The factors of coastal zone change occur from both natural

GLOSSARY (CONTINUED)

		factors and man-induced activities (European Commission, 2004).
Economic vulnerability	-	Assessment of economic losses due to coastal erosion by computing the value of threatened land, building, structure and social services from threatened beaches(recreational services). (IPCC, 1997)
Geoindicators	-	A definition by the International Union of Geological Sciences (IUGS). Geo-indicators mean "measures of surface or near-surface geological processes and phenomena that vary significantly over periods of less than 100 years and they are applied to a wide variety of environments. The geo-indicators of coastal zone impact assessment are consist of erosion & accretion area, erosion &accretion rate, beach slope, width of beach, mangrove, coastal construction, strong wind-wave, river mouth location, beach morphology and sediment type (Bush, 1999; Berger, 1996, 1997).
Long-term	-	A study on coastal zone change in more than 10 years
Coastal erosion	-	The process of wearing away material from a coastal profile due to imbalance in the supply and export of material from a certain section. It takes place in the form of scouring in the foot of

GLOSSARY (CONTINUED)

		the cliffs or dunes or at the subtidal foreshore. Coastal erosion takes place mainly during strong winds, high waves and high tides and storm surge conditions, and results in coastline retreat and loss of land (Mangor, 2004)
Shoreline	-	An idealized definition of shoreline is that it coincides with the physical interface of land and water (Dolan et al., 1980 cited in Boak and Turner, 2005)
Spatial modeling	-	A methodology or analytical procedures applied with ModelBuilder/ArcGIS. It is used to automate GIS processes by linking data input, ArcGIS tools/functions, and data output. It can be automated and rerun without using any code
Social risk	-	Social impact assessment along Hat Chao Samran focused on analysis of resettlement risks due to coastal erosion along the beach.
Sustainable for coastal zone management	-	The balancing of environment, social and economic and should be concerned taking a long-term view and enhancing the environment for future generation (Environment agency, 2007; Munasinghe, 1993:3)

CHAPTER I

INTRODUCTION

Statement of the Problem

The coastline of Thailand is 2,614 km long, including areas along the Gulf of Thailand (1,660 km, 17 provinces) and the Andaman Sea (954 km, 6 provinces). There are more than 12 million people living along the coast (Department of Marine and Coastal Resources, 2010). Therefore, the coastal regions are significant residential, industrial, and commercial areas, while also supporting tourism and serving as essential habitat for marine life. Coastal regions are important to the ecosystem with their abundance of natural resources having economic and social value.

The manner in which these lands are utilized, however, has changed over recent decades. Development or expansion of infrastructure has resulted in geo-morphological imbalances in areas along the coastline affected by seasonal changes in currents and wind waves, causing some coastal regions to be eroded with great losses of coastal land, government property, and residential land (Office of Natural Resources and Environment Policy and Planning, 2009). Moreover, in many coastal communities, the tourism industry is the mainstay of the local economy. Unfortunately, both tourism resources and the tourism industry are now threatened by dramatic coastal changes induced by human activities (Allen and Potts, n.d.). 95% of land use decisions are made at the local level (Kleppel, 1998). The impacts of land use change for any purpose and exploitation of the coastal zone could be factors regarding coastal zone changes (FAO, 2007; European Commission, 2004; DMCR, 2012; Pearce 1995;Fedra and Feoli, 1998).

At present, the coastal region suffers from severe erosion due to a complex variety of long-term cumulative issues. There are no effective methods in place to prevent erosion along the coastline, resulting in enormous losses to coastal land and properties. An environmental assessment by the World Bank (2007, cited in Siripong, 2010) found that coastal erosion is one of the most serious environmental problems in Thailand. Thailand's coastal areas are eroding at a rate of over 1–5 m/yr. On average, the rate of land loss is 2 km^2/yr and economic losses are as great as 6,000 million baht. Several studies of coastal zone change in Thailand having been conducted. The Geo-informatics and Space Technology Development Agency (2010) used multi-satellite images to appraise coastline changes and identified the five areas in Thailand with the greatest erosion as Samutprakarn, Chumporn, Pattani, Samutsakorn, and Petchaburi Provinces with a total loss of coastal land of15 km^2during 1999–2009; the erosion rate in these critical areas was 7.66–13.86 m/yr. The Department of Mineral Resources, Ministry of Natural Resources and Environment (undated) studied coastal erosion in the Gulf of Thailand and found severely eroded land along 200 km of coastline, with an average erosion rate of 5 m/yr. Siripong (2010) evaluated coastline changes in Thailand through remote sensing and revealed that coastline changes over the previous decade were 15.8% along the Andaman sea and 37% along the Gulf of Thailand. Thampanya *et al*. (2006) concluded that overall, net erosion prevailed (1.3 ± 0.4 m/yr). The Gulf of Thailand coastline on the east coast was found to be more dynamic than in the west (43% vs. 16%). Rates of erosion were also higher than rates of accretion, 3.6 vs. 2.9 m/yr and 2.6 vs. 1.5 m/yr, respectively.

In response to these concerns, the Department of Marine and Coastal Resources (DMCR), Marine Department (MD), and local agencies have taken steps to protect coastal areas through many protective measures, including soft approaches such as beach nourishment, mangrove afforestation, and setbacks and hard solutions such as breakwaters, seawalls, and groins. However, the problem persists at increasingly intense levels. The Office of Natural Resources and Environment Policy and Planning (2009) concluded that most erosion is anthropogenic induced, e.g., through inappropriate land use, port and dam construction, and overuse of groundwater resources. Food and Agriculture Organization [FAO], (2007) concluded that erosion worsens when the applied countermeasures (hard or soft structural options) are inappropriate or improperly designed, built, or maintained and when the effects on adjacent shorelines are not carefully evaluated. Solutions to coastal erosion challenges must be designed for each problem area. As in Thailand, Sangmanee Isarapong, Mayor of Chao Samran, announced that the Hat Chao Samran District had coordinated with the Marine Department and allocated approximately 220 million baht to build breakwaters to prevent erosion and to maintain the entire beach (Matichon, 2007). The breakwaters were completed in 2008. In 2012, GISTDA, using ALOS and THAICHOTE images, discovered that construction of the breakwaters had increased the beach area, but the shape of the beach had changed. Implementation of this measure prevented erosion of the beach in this area, but may have had other impacts, such as the enjoyment of the beach by tourists and land loss in adjacent beach areas.

Siripong (2008) concluded that decision-making related tothe eroding beaches of Thailand should be based on systematic studies of physical processes and considering the consequences and impacts of construction, including potential exacerbation of problems. Ultimately, planning and management of coastal erosion should use the most sustainable practices taking into consideration both natural and man-made factors. For example, Dean (2002) based his design of a beach nourishment program on goals that included a larger beach for recreation, storm protection, aesthetics, and environmental improvement.

We selected Hat Chao Samran, Petchaburi Provinceasthe study area for several reasons. This area has a long, straight sand beach oriented north-south and directly affected by seasonal monsoons, which are one of the natural forces causing coastal erosion. North of Hat Chao Samran is LeamPak Bia, a mangrove area that could provide soft protection against coastal erosion; to the south isHat Chao Samran, which has many breakwaters as hard protection. Accordingly, this area provides a good comparison or monitoring location for changes in adjacent beach areas associated with soft and hard prevention measures. In addition, Hat Chao Samran is adjacent to Cha-am Beach, which is the one of most well-known beaches in Petchaburi and is therefore rapidly experiencing economic growth. This may be a factor affecting coastal zone change and, on the other hand, erosion may cause socioeconomic impacts in this area (DMCR, 2012).

Although there have been many studies of changes in the coastal zone, including factors affecting coastal zone change, technologies for evaluating impacts to coastal areas, and indicators of socioeconomic impacts, developing a sustainable approach to managing coastal areas remains a challenge. Also some previous research on land use and coastal zone change at this level is not adequate and used conventional methodologies that have some limitations regarding spatial detection, long-term monitoring, assessment, modeling (assimilation), and prediction of coastal zone change (Allen and Potts, n.d.; Pearce, 1995; Klinebubpha and Pumijumnong 2011). A major problem with the most common statistical modeling technique and standard applications of regression when applied to spatial data is that the processes being examined are assumed to be constant over space – that is, one model fits all. In contrast solutions to coastal erosion challenges must be designed fo reach problem area. By far, the most common statistical modeling technique is regression, and it is used mostly in the social sciences. The combination of social sciences and scientific research using spatial analysis is still not widely used.Thus, these past studies are insufficient to address changes in coastal areas, in terms of obtaining long-term continuous data, combination of social sciences and scientific research and integration of spatial analysisfor developing a sustainable coastal zone approach.

This study focused on evaluating the causes and effects of beach changes over the long-term at Hat Chao Samran, Petchaburi Province, using geo-indicators and socioeconomic indicators together with spatial analysis. Coastal zone changes in adjacent areas were also included in the study. The results illustrate gaps in coastal research and planning activities in a framework for sustainable coastal zone management. Development of the spatial sensitivity model introduced in this study provides a new geo-processing tool that will streamline workflow and can be reconfigured for efficient analysis of various regions. The spatial model takes into account several interdisciplinary factors to promote sustainability in coastal zone management and can be applied to other coastal areas of Thailand.

Objectives

1. To investigate coastal erosion in the study area
2. To establish a predictive model for long-term shoreline changes
3. To define sensitivity indices for coastal zone change
4. To develop a spatial model for sustainable coastal zone management

Research Contributions

1. A coastal risk map showing changes in the beach at Hat Chao Samran, Petchaburi Province
2. Predictive model that predicts changes in the shoreline over the short, medium, and long term
3. Spatial model addressing the coastal environment and social and economic aspects of coastal zone management that can be applied to other coastal areas of Thailand
4. Initial guidelines for sustainable coastal zone management

Hypotheses

It is hypothesized that management of coastal erosion over the long term can be practically addressed using three factors (rather than one criterion), i.e., the coastal environment and social and economic indicators, to enhance sustainable decision-making.

Scope of the Study

This study used an interdisciplinary approach to evaluate the causes and effects of coastal zone change by considering the impact to the coastal environment and economic and social factors. The study area included a shoreline distance of about 7 km along Hat Chao Samran, Petchaburi Province, as well as 2 km to the north and 2 km to the south, to investigate factors affecting erosion. The methodology included analysis of natural and anthropogenic factors affecting coastal erosion by collecting oceanographic and meteorological data from the field, using a time series of multi-satellite images, and integration of geo-informatics technology to analyze coastal erosion conditions, predict future conditions over different time periods, identify relevant indicators affecting coastal erosion, and establish a spatial model for coastal erosion management. The details of this framework are shown in Figure 1.

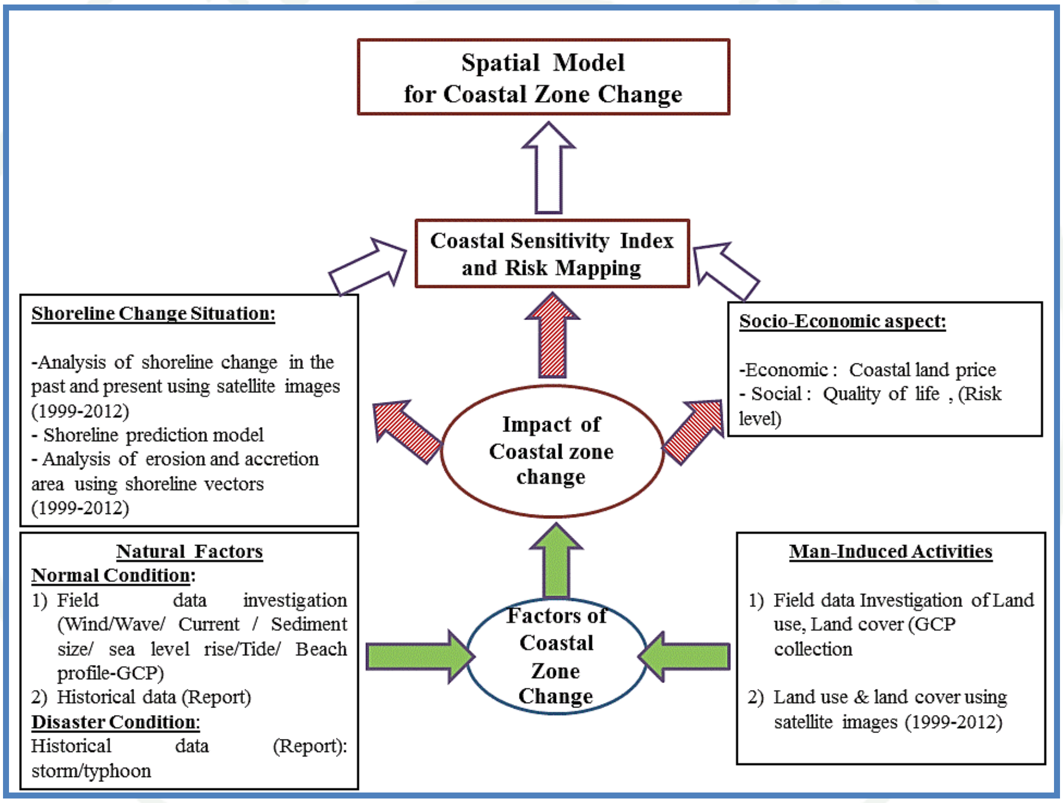


Figure 1 Research framework, including investigation of factors affecting coastal zone change, both natural and anthropogenic, development of a predictive model for shoreline changes, identifying factors that affect coastal zone change and socioeconomic impacts, determining and mapping coastal risk areas, and developing a spatial model for coastal zone management

CHAPTER II

LITERATURE REVIEW

Factors affecting Coastal Areas

Coastal processes are natural phenomena that affect the coastline. During the monsoon season, strong winds and high waves move sand from the beach to accumulate on sand bars underwater, while during calm periods, sand moves back up onto the beach. These processes result in beach equilibrium over the seasons (Figure 2)

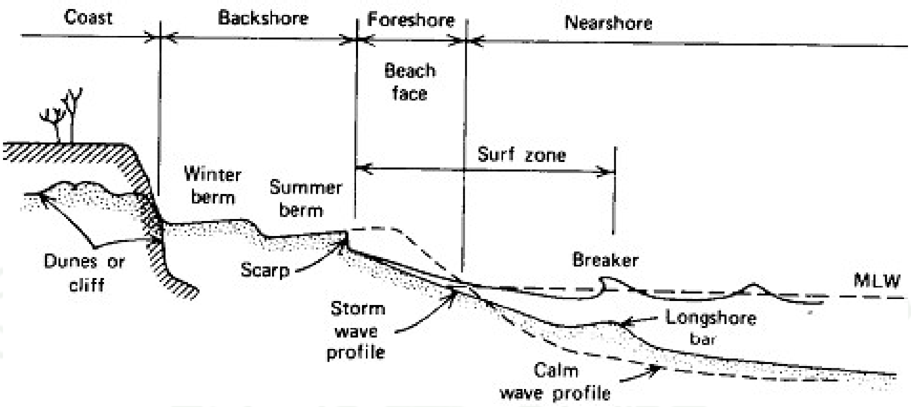


Figure 2 Physical changes in the coastal zone
Source: Sorensen (1991 cited in Rithpring 2002)

More permanent coastal zone changes areca used by both natural and anthropogenic processes, discussed below.

1. Natural factors

1.1 Soil and sediment movement

Changes in the coastline of Thailand, both erosion and accretion, may result from movement of soil and sediment from one place to another to maintain equilibrium. If the coastal condition is stable, the net sediment transport is zero and the coastal zone does not change. In addition to coastal processes that can change the coastal zone, geologic processes may occur such as subsidence and emergence of land. The frequency and amount of sediment transport is related to several factors, such as wind-waves, currents, tidal forces, beach slope, groundwater, geological structure, storms, suspended sediment, etc. (Rithpring, 2002).

1.2 Sea level rise

Pilkey and Yong (2009) stated that sea level rise plays an important role and will inevitably increase shoreline erosion. The sea level has change many times in the geologic past; however, the impact in the present is unprecedented due to the large human population and associated infrastructure located in coastal areas. Choowong (2002) discussed the evolution of the coastal plain in the Gulf of Thailand using reliable evidence of sea-level changes and concluded that coastal morphological maps, sequence stratigraphy of coastal sediments, and indicators of sea-level change all confirmed the process of coastal evolution in the Gulf of Thailand. DMCR (2012) analyzed and simulated the impact of sea-level rise on coastal areas of the upper Gulf of Thailand. They predicted that the sea level will rise over the next 10 yr by 5 mm/yr and subsidence will be about 14 mm/yr; thus, the cumulative risein the sea level will be 190 mm.

1.3 Wind and waves

Coastal erosion caused by wind and waves is already a widespread and a serious problem in many areas of Thailand and other coastal countries. The most vulnerable area in the Baltic sea region are simultaneously affected by direct storm-induced surges and wind-generated storm waves (Kurennoy and Ryabchuk, 2011). Impacts of waves on the coastal zone have been observed in many areas of the eastern Gulf of Finland for a long time (Orviku et al., 2003). This high rate of coastal erosion results from the specific features of this area: geomorphology, shallow seas, and the local wave field (Ryabchuk et al., 2009; Soomere et al., 2010).

1.4 Circulation patterns

Coastal currents are important elements of studies of nearshore geomorphology, hydrology, and sedimentary processes. Klemas (2012) stated that ocean currents influence global heat transport, weather and climate, larval transport, distribution of water pollutants, sediment transport, and marine transportation. Surface currents are primarily caused by wind friction as the wind moves over the water. The speed of a current will be approximately 3–4% of the generating wind speed.

1.5 Extreme weather events and tsunamis

Coastal erosion is a major problem not only in Thailand but in coastal zones around the world. The most important causal factors depend on the region. Scleupner (undated) evaluated the potential for regional coastal impacts such as erosion and inundation caused by extreme weather such as tropical storms and hurricanes along the northwestern shore of Martinique. In that area, approximately 53 storms had caused extensive damage to human coastal resources. Wave heights over 9 m were commonly associated with erosion and inundation. Park and Edge (2011) confirmed that over-wash by remote storms was an important contributor to continued beach erosion in the study area. Erosion caused by direct landfall of storms had significant impacts as well.

2. Anthropogenic activities

As a transition area between the land and the sea, the coast is characterized primarily by geologic factors. In many cases, the coastal region is important for human activities, including cultural, economic, fisheries, industry, tourism, and social (Rais and de Boois, 1997, cited in Siregar and Doydee, 2006). As human activities occur along the coastline such as building residences, aquaculture, and changes in coastal land use, these activities disturb the equilibrium of coastal processes, particularly construction of jetties, seawalls, groins, breakwaters, landfills, etc. The Office of Natural Resources and Environment Policy and Planning (2009) reported that many coastal areas in Thailand are considered vulnerable to erosion. Studies have shown that most of the causes are anthropogenic, e.g., inappropriate land uses, port and dam construction, and overuse of groundwater resources. Some natural factors do exacerbate coastal erosion, including high wind-waves and seasonal storm surges, particularly during September–November. However, climate change may become a more important factor affecting coastal erosion in the future.

Coastal Erosion Impacts and Methods Used to Study the Coastal Zone

1. Changes in coastal areas

Thailand has a coastline of more than 2,600 km along the Gulf of Thailand and the Andaman Sea. The coastal area includes 23 provinces, increasing the potential impacts of the loss of coastal land. The coast of Thailand has experienced severe erosion over the past 10 yr, particularly along the Gulf of Thailand coast, with great loss of coastal land, coastal resources, economic productivity, residential property, and social amenities. The factors contributing to coastal erosion include both natural processes and human activities.

In 2010, GISTDA evaluated coastal erosion along the coast of Thailand during 1999–2009 using various types of satellite imagery and found that the five areas with the most erosion were Samutprakarn, Chumporn, Pattani, Samutsakorn, and Petchaburi Provinces with losses of coastal land of about 4.78, 3.24, 2.70, 2.52, and 2.50 km^2, respectively. The highest erosion rates were 13.86 m/yr in Samutprakarn, 10.29 m/yr in Samutsakorn, 9.89 m/yr in Nakornsrithamarat, 7.80 m/yr in Bangkok, and 7.66 m/yr in Chachengsao Provinces (Figure 3).

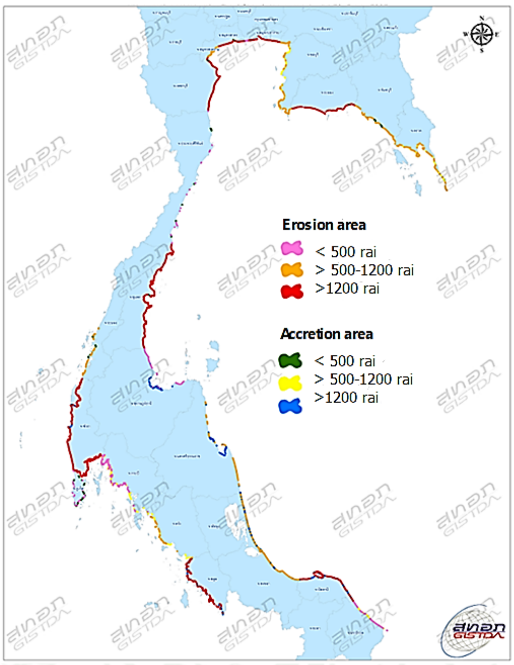


Figure 3 Erosion and accretion along the coast of Thailand investigated using LANDSAT-5TM during 1999–2009

Source: GISTDA (2010)

Using THEOS/ALOS imagery, GISTDA (2012) studied changes in the shoreline of Phetchaburi Province (12º55′4.93″ N, 99º37′50.77″ E) with a total area of 6,255.138 km^2 divided into eight administrative districts: Muang Phetchaburi, Amphoe Khao Yoi, Amphoe Nong Ya Plong, Amphoe Cha Am, Amphoe Tha Yang, Amphoe Ban Lad, Amphoe Ban Laem, and Amphoe Kaeng Krachan. Coastal erosion of 91.49 km was reported, affecting nearly all areas of Phetchaburi. Areas of severe erosion (10 m/yr) were found in the Ban Laem district. The influence of subsidence on coastal erosion was also analyzed using DinSAR software. Subsidence in Petchaburi during 1 February 2010–19 September 2010 was 0.64 m/yr and during 27 January 2008–19 September 2010 was 2.68 m/yr.

The Regional Environmental Office 8 (REO 8) (2010) concluded that coastal erosion has been a major problem in the coastal provinces during the past few decades. A recent study identified three coastal areas in Petchaburi and Prachuap Kiri Khan as undergoing critical damage or “hot spots” with average erosion rates of 7–10 m/yr.

The geoinformatics technique integrates remote sensing, a geographic information system (GIS),and global positioning system (GPS) and is practical and attractive for use in research and management of coastal areas. Klemas (2011) described the use of multispectral and hyperspectral imagers, thermal infrared scanners, microwave radiometers, radar imagers, scatterometers, altimeters, and airborne light detection and ranging systems to obtain the required spatial, spectral, and temporal resolution for coastal ecosystem data such as coastal land cover, coastal currents, ocean waves, wind speeds, sea surface height, and bathymetry.

Application of GIS and remote sensing (RS) technology provides spatiotemporal information that is long-term and continuous. Thus, geoinformatics is a useful and efficient technology for management, planning, and decision-making to mitigate coastal zone changes. An example of investigation and separation of land and water areas is shown in Figure 4; various sources of data can be used, such as photographs, coastal maps, airborne images, coastal surveys, GPS, digital elevation data, and satellite data (Boak andTurner, 2005).

Figure 4 Determining the physical boundary of a coastal zone using remote sensing data

Source: Boak and Turner (2005)

The shoreline is one of the most important and dynamic features affecting computation of shoreline changes and associated environmental changes. Mapping of tidally affected shorelines has formerly been very costly. High-resolution satellite and airborne imagery have the capacity for stereo imaging and can be used to extract instantaneous shorelines with high accuracy and at low cost (Li *et al.*, 2002).

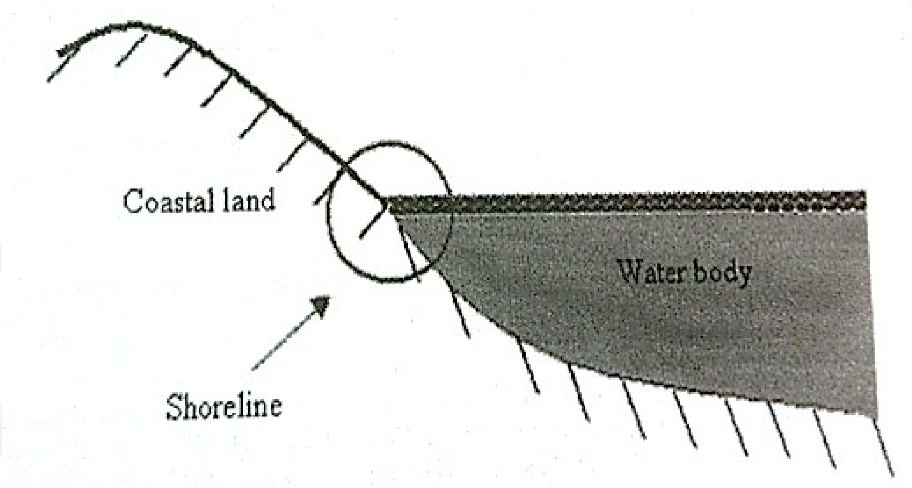


Figure 5 A shoreline defined as the linear intersection between the coastal land and the water body
Source: Li, Ma, and Di (2002)

The accuracy of the shoreline also depends on the resolution of the satellite images; Lupino*et al.* (2004) used high-resolution images such as 0.7-m QUICKBIRD and 2.5-m SPOT to extract the shoreline. Satellite images have high potential for use in impact assessments of coastal erosion to determine the size and location of the area, and provide one tool for policy development for coastal zone management and planning. Li*et al.* (2001) applied coastal spatial data such as high-resolution satellite images for investigating and monitoring coastal erosion areas and for spatial modeling using a dynamically segmented linear model. This represented an essential development in decision-making systems for coastal zone management.

Elkoushy and Tolba (2002) also investigated shoreline changes due to erosion and/or sedimentation by analysis of aerial images and comparing the results with those obtained from conventional surveying methods. Four primary sources of high-resolution satellite imagery were evaluated: 10-m spatial resolution SPOT, 5-m spatial resolution IRS, 2-m spatial resolution SPIN2, and 1-m spatial resolution

IKONOS. The shoreline was extracted using GIS by manually selecting the correct boundaries. Changes in the shorelines were noted due to natural processes (e.g., wind-waves, bathymetric changes, and long-shore sediment transport) as well as man-made structures (e.g., the detached breakwaters at El-Gamil, Egypt). The results showed that data obtained from aerial images could be used with GIS to study shoreline changes over time across a wide area, which can assist in predicting shoreline changes.

Masele and Mayunga1 (2000) investigated the rate of erosion along the coast by focusing on the causes of coastal erosion, such as winds, tides, and land use. In addition, they suggested methods for using GIS as a tool for geospatial analysis, development of integrated coastal zone management plans, and distribution of geospatial data.

There are many high-end technologies that can be used to increase the accuracy of coastal mapping. For example. Long and Pe'eri (2011) reported that airborne LIDAR bathymetry and topographic LIDAR are standard tools for coastal mapping that are utilized in mapping programs around the world, such as the National Shoreline Program of NOAA and the National Coastal Mapping Program of the U.S. Army Corps of Engineers. Using a series of elevation and/or imagery data sets for the same location can also identify trends in specific environmental processes.

Because of the dynamic nature of coastal land, shorelines are not truly stable either over the long-term or short-term; thus Elaksher (n.d.) integrated multiple remote-sensing measurements, spatio temporal databases, coastal hydrological modeling, and GIS to study the impact of sea level rise on shoreline geometry to support coastal decision-making. Shorelines were generated using a coastal terrain model (CTM) and a water surface model (WSM). The CTM was generated using multiple remotely sensed datasets and spatiotemporal databases, while the WSM was produced using a coastal hydrological model.

2. Impacts to coastal resources and socioeconomic benefits

The coastal zone provides substantial social, economic, and ecological benefits. The coastal zone in the study area is composed of sea grass beds, mangroves, coral, industry, aquaculture, and tourist areas. These resources and benefits are sensitive to change as a result of natural processes and anthropogenic activities. Development of coastal areas must consider impacts to coastal resources, long-term socioeconomic benefits, land use conflicts, and development of renewable resources.

The economic value of marine resources is estimated through two main methods, direct value and indirect value (Limpasaichon, 2003). There are six primary techniques for assessing the value of marine resources:

- Market based technique
- Marginal effect on production technique
- Cost-based technique
- Contingent Valuation Method (CVM)
- Travel Cost Method (TCM)
- Hedonic Price Method (HPM)

DMCR (2012) investigated the impact of sea level rise on the coastal zone in the upper Gulf of Thailand and evaluated environmental losses (mangroves) and economic losses (land value). The loss of mangroves and reduction in land value due to sea level rise was predicted over the next 10, 20, 50, and 100 yr. In the next 100 yr, Samut Prakan Province is predicted to experience the greatest loss of mangrove area, amounting to about 1,607,548,902 baht. Petchaburi Province is predicted to have the second greatest loss of mangroves, with economic damages of about 1,018,751,786 baht. The average change in land values per year was predicted to be highest in Petchaburi Province of 24.36 baht/m^2 and lowest in Samutsakorn Province at 5.11 baht/m^2.

Bayani (2009) studied economic issues associated with use of the coastal zone and conducted a risk analysis and economic assessment for a case study of coastal erosion in the Philippines. This study considered three types of damages due to coastal erosion consisting of loss of property, loss of structures and buildings, and loss of public resources such as mangroves, sea grass beds, aquaculture, and recreation. The study estimated the economic vulnerability of San Fernando and Bauang, La Union Province to coastal erosion. Essentially, economic vulnerability can be interpreted as the potential damages due to coastal erosion under the "no action" strategy or assuming the status quo, including the three categories described above. In addition, potential lost income from tourism, agriculture, and aquaculture was computed as an initial estimate of the impact of coastal erosion on economic activity.

Corne (2009) provided an alternative point of view that there is an increased need for surfing resources worldwide as participation in the sport grows and noted both enhancement and reduction in wave quality after construction of coastal protection. He found that coastal protection generally has an effect on surfing resources that may be positive or negative in terms of wave quality and beach crowding.

Klein and Osleeb (2010) determined the economic benefits of ocean beach enhancement projects on several important tourism-dependent counties in Florida, USA and linked an exploratory spatial data analysis of the tourism sector with a statistical study of the economic determinants of coastal tourism in Florida. This study used a two-equation model of beach nourishment and coastal tourism that consisted of 1) a log it model to estimate the likelihood that a coastal Florida county will be the site of beach nourishment activity as a function of supply-side variables—i.e., the USDA-ERS Natural Amenities Scale, water temperature, water quality, and quantity of recreational beaches (Figure 6) and 2) a hedonic price model to identify influences on tourism revenue over the 1970–2000 study period using both supply-side and demand-side variables.

The *logit model* of the location of beach nourishment projects is specified as

PROJCTY = $\beta_0+\beta_1$AMENITY+β_2JANWAT+β_3EXCWQ+β_4BEACHKM+ε

Where;

PROJCTY = 1 if the county was the location of at least one beach nourishment project during the 1970–2000 study period and 0 otherwise;

AMENITY = the value of the USDA-ERS Natural Amenity Scale, measured in standard deviations above or below the mean for all U.S. counties (+, the incremental value of well-maintained beaches is greater in locations that are rich in natural amenities);

JANWAT = the average January water temperature (+, an indicator of the length of the tourism season);

EXCWQ = the number of times that the U.S. Environmental Protection Agency water quality standards are exceeded (2, poor water quality is a negative amenity); and BEACHKM5 the length of beaches in km (+, a measure of the capacity to accommodate tourists).

The reduced form equation of *the ordinary least squares (OLS) model* of the change in tourism earnings is

LNDTOUR = $\beta_0+\beta_1$PROJHAT+β_2LNGRAV+ β_3LNAIRDIS+ε

Where;

LNDTOUR = the natural log of the change in earnings in the tourism sector from 1970 to 2000, in current dollars;

PROJHAT = the estimated value of the dependent variable in the logit model of beach nourishment, representing the contribution of beach nourishment projects to the tourism sector (+, we expect that destination counties with well-maintained beaches will be relatively attractive to tourists);

LNGRAV = the natural log of the county gravity model result (+,a measure of the size of the local tourism market and the accessibility of the beach county); and

LNAIRDIS = the natural log of the distance from the county centroid to the closest major airport, in miles (2, a measure of the accessibility of the county to nonlocal tourists, indicating the negative impact of distance)

3. Coastal modeling

3.1 Shoreline change model

Himmelstoss (2009) explained Digital Shoreline Analysis System (DSAS) 4.0 that it is freely available software developed by USGS. DSAS functions within the Environmental Systems Research Institute (ESRI) Geographic Information System (ArcGIS) software. DSAS computes rate-of-change statistics for a time series of shoreline vector data. Each shoreline vector represents a specific point in time and must be assigned a date in the shoreline feature-class attribute table. The measurement transects cast by DSAS from the baseline intersect the shoreline vectors. The points of intersection provide location and time information used to calculate rates of change. The distances from the baseline to each intersection point along a transect (Figure 6) are used to compute the selected statistics. DSAS has been widely used for studies of changing shorelines (Harris et al., 2009), predictive accuracy of the shoreline change rate (Genz et al., 2007), setback lines and shoreline evolution (Shoreline Study Program, 2010), historical shoreline mapping (Thieler and Danforth, 1994).

Figure 6 The distance from the baseline to each measurement point. It is used by DSAS in conjunction with the corresponding shoreline date to compute change-rate statistics

Source: Himmelstoss (2009)

Martinez (2007) applied the logarithmic spiral model to assess shoreline change in Concón and Algarrobo bays, central Chile. Using this method, the shoreline was determined by identifying the high tide line from all of the sources used (aerial photographs, field work). When combined, notable points or common characteristics in all of the photograms could be identified, providing necessary georeferencing checkpoints. Georeferenced aerial photos (geoTIFF) were generated using the export feature of ERDAS software and the UTM coordinate system in geodetic datum WGS 84. The geoTIFF images were imported into AUTODAC Land Development software for vectoring the coastline; a .dxf file was generated for each vectored image. Finally, each .dxf file was exported to ShapeFile (.shp) format to visualize and quantify the changes in the coastline using ArcGIS 8.1. The logarithmic spiral model was applied using the equation I = aeΦcotgb where a and b are constants and Φ is the angle of the polar azimuth (0–360°). A series of values for each of the constants (a, b) was tested, assuming values for the angle Φ. Finally, values for (a, b) were determined that established the best fit for the study area shoreline. However, using the logarithmic spiral adjustment model, it is difficult to unequivocally the location of the diffraction pole that gives rise to the θ angle, allowing simulation of the logarithmic spiral form.

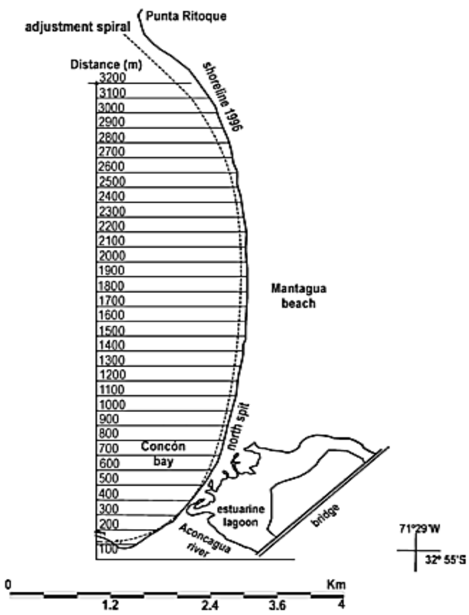


Figure 7 Adjustment model applied to Concón Bay, Chile
Source: Martinez C. (2007)

3.2 GIS-based model

ModelBuilder is an application that can be used to create, edit, and manage models. This application is a built-in function of ArcGIS Desktop that strings sequences of geoprocessing tools together. This tool can streamline workflow and allow models to be reused, improving efficiency (ESRI China, 2011). The benefit of ModelBuilder/ArcGIS for coastal study is the development of generic models that can be used for geoprocessing linear features. This GIS analysis model can also be used to repeat the creation of binary and ranking models (Figure 8).An additional advantage to using ModelBuilder is that once the steps are visually diagrammed and run, the model as a whole can be saved and shared among multiple users (Chaaban et al., n.d.).

Espey (n.d.) used this technique with two-dimensional maps and GIS to work with snapshots of a shoreline that is perpetually changing. The project evaluated the consistency of combining a shoreline definition based on mean high water (MHW) tidal datum with a delineation technique that incorporates automation using digital elevation models (DEMs). Automatic extraction of a tidal datum-referenced shoreline from elevation data can then be accomplished by creating and implementing a GIS model using ArcGIS 9 ModelBuilder.

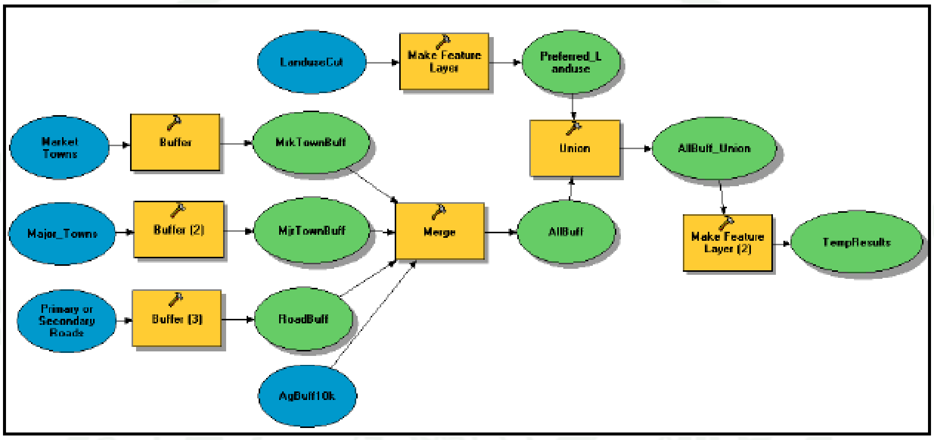


Figure 8 Running several variations of an analysis using ModelBuilder
Source: Chaaban *et al*. (n.d)

Scleupner (n.d.) developed a GIS-based model through spatial analysis and scenario modeling of coastal sensitivity to flooding and erosion; potential expansion of the impact area by extreme storm events and tsunamis was also evaluated. Five parameters were chosen that influence the coastal risk of flooding and erosion: 1) relative elevation, 2) erodibility, 3) natural shelter of the coastal segments, 4) coastal exposure to wind regimes, and 5) accumulation.

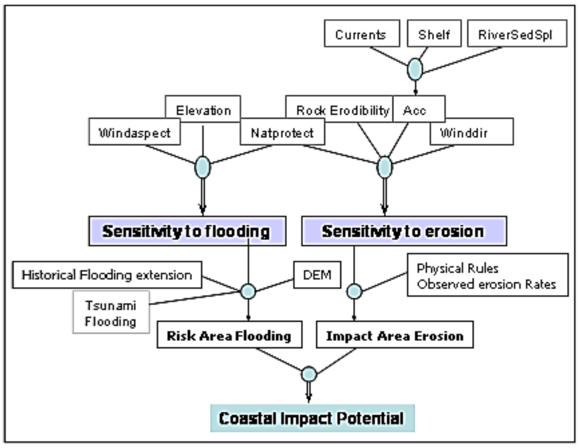


Figure 9 The methodological structure of the GIS-based model.
Source: Scleupner (n.d.)

Rocha et al. (2007) studied the growth and development of the Municipality of Almada (Portugal) by modeling spatially dynamic and naturally complex phenomena in coastal areas that are important for developing an innovative strategy for physical planning and environmental management. This study presented a method for simulating coastline evolution (integrating land use/cover), linking neural networks and cellular automata in a GIS environment. This technique enables understanding of land use and occupational phenomena in coastal areas subjected to strong urban pressure.

3.3 Integrated coastal model

Brommer and Bochev-Van der Burgh (2009) stated that combining geologic and morphological data requires a multidisciplinary approach and hence, the development of a common language. They described an "integrated coastal model" that illustrates gaps in coastal research and planning activities in the context of sustainable coastal management. Fluvial processes (hinterland characteristics), changes in the sediment budget (sediment transport processes), and human activities are currently omitted in forecasting long-term, large-scale coastal changes and are therefore indicated with a cross. Currently, models that simulate the effects of human interference are poorly developed. However, the impacts of human activities on long-term coastal evolution should be accounted for.

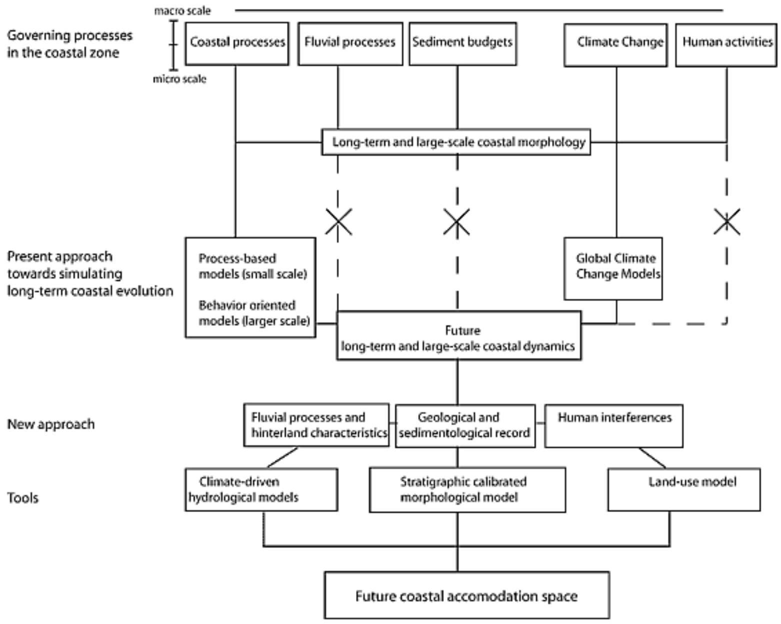


Figure 10 The integrated coastal model, a multidisciplinary approach for future coastal development scenario-building

Source: Van der Burgh and Brommer (2009)

Sobchuk (n.d.) developed a basic, universal Geological Hazards Environmental Emergency (EE) and Risk Management (RM) model for management and forecasting the state of the geologic environment and processes in areas influenced by sea level changes, as well as for forecasting geologic hazards and emergencies and estimating geo-environmental risks. The methodology is designed to detect developing negative geological processes for the test sites selected as well as for general use in coastal areas, based on universal simulation models with remotely sensed data as input. The study integrated analysis of heterogeneous data; methods and software tools for combined analysis of raster (remotely sensed data) and vector data (ground-based point data) were developed to obtain more complete information. The model is based on factor analysis and image recognition theory.

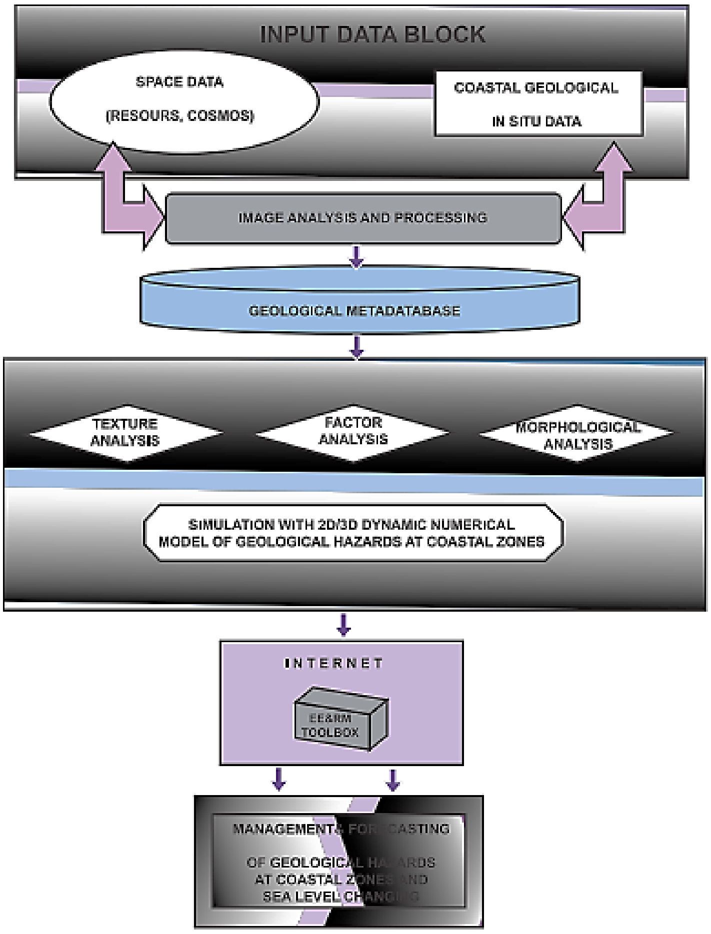


Figure 11 Overview of the Geological Hazards EE and RS model
Source: Sobchuk (n.d.)

4. Sustainable coastal zone management

To provide a scientific basis for decision-makers, it is necessary to comprehensively assess the status of regional development with regard to the economy, resources, and environment (UNDP, 2007). To develop a sustainable coastal development and implementation plan with effective beach erosion control and coastal ecosystem protection strategies, scientists and coastal managers need information on long-term and short-term changes taking place along the coast (Klemas, 2009, cited in Klemas, 2011). There are many technologies and methods available for application to sustainable coastal zone management.

4.1 Sustainability assessment

Sustainability of the coastal zone refers not only to maintaining coastal equilibrium and preventing erosion of beaches, but also to the use of current resources to meet present needs without adversely affecting the environment or the economic ability to produce goods and services in the future (Hartwick and Olewiler, 1998). Munasinghe (1993) suggested that when sustainable development is the ultimate goal, balancing of environment, social, and economic systems is required. To assess sustainability, Mueller (1997) suggested environmental or extended cost-benefit analysis (ECBA), multi-criteria decision mechanisms (MCDM), and sustainability indicator analysis.

The European Regional Development Fund (2005) reported that:

> … Multi-criteria analysis (MCA) is an approach for choosing from a set of alternatives in such complex, multiple objective situations and to incorporate all social, economic and ecological costs and benefits, measured on different measurement scales, monetary and not monetary, quantitative and not quantitative.

The European Regional Development Fund (2006) described the most commonly used methods as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA). CBA and CEA use economic efficiency criteria (net present value, benefit-cost ratio) in the appraisal of projects, whereas MCA includes additional criteria such as equity and ecological and distributional aspects.

One definition of sustainable development is that the coastal zone not only meets increasing demand, but also protects the ecology and environment, without prejudice to future generation's access to adequate food security (Brundtland, 1987). Yu et al. (2010) conducted a case study of sustainable development for the coastal city of Yantai, China from 1998 to 2007, using a methodological framework based on 36 indicators and three composite indices from among environment, economy, and society subsystems. The method used three models representing integrated coordinate degree (DCZ), developmental sustainability (SCZ), and sustainable development degree (KSD) (Niu, 1999; Xiong, 2007, cited in Yu et al., 2010). DCZ measures the level of development and degree of coordination among ENS, SOS, and ECS; SCZ measures the level of sustainability of the three subsystems; and KSD comprehensively measures the level of development, sustainability, and status of the coastal zone.

In this study, a combination of subjective and objective methods was employed to develop a weighted index system using the analytical hierarchy process (AHP) and principal component analysis (PCA) methods. A variety of pressures and their trends were analyzed (climate change, population and tourism, port development, hydrocarbon and marine aggregate extraction and pollution). All of these factors were examined in the context of sustainable use of coastal resources and interdisciplinary ecological economics (Turner *et al*., 1998). The Integrated Coastal Zone Management (ICZM) was a combination of ecosystem function-based valuation and evaluation methods and the Pressure-State-Impact-Response (P-S-I-R) technique and Driving Forces-Pressures-State-Impacts-Responses (D-P-S-I-R framework) (Kristensen, 2004).

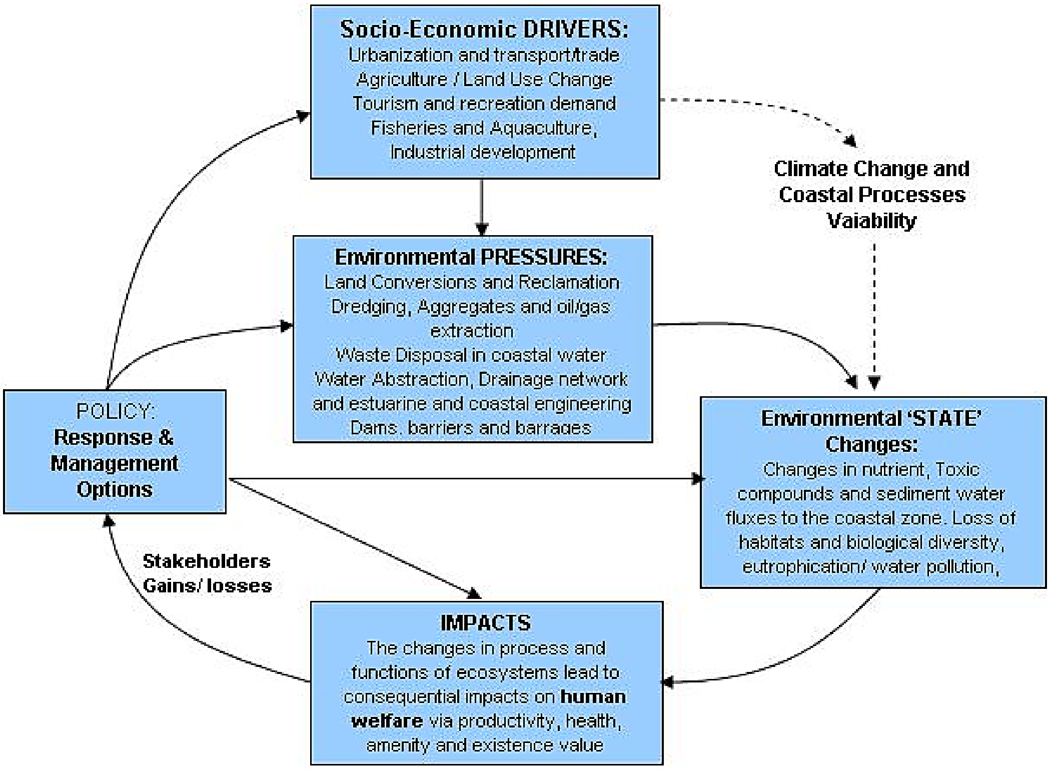


Figure 12 D-P-S-I-R framework for coastal areas

Source: Turner *et al*. (1998) and Kristensen (2004)

4.2 Geoindicators assessment

Bush (1999) and Berger (1996, 1997) described geoindicators as: Geoindicators is given definition by the International Union of Geological Sciences (IUGS). Geoindicators mean "measures of surface or near-surface geological processes and phenomena that vary significantly over periods of less than 100 years and they are applied to a wide variety of environments. Geoindicators has widely used for environment. In case of coastal zone, it is useful for common coastal hazard and mitigation the properties damage. Using geoindicators are sparing time, low cost of field survey and benefit for management and planning of coastal zone. The geoindicators of coastal zone impact assessment are consist of erosion & accretion area, erosion &accretion rate, beach slope, width of beach, mangrove, coastal construction, strong wind-wave, river mouth location, beach morphology and sediment type.

4.3 Coastal vulnerability indices

Boruff*et al*. (2005) examined the vulnerability of US coastal counties to erosion by combining a socioeconomic vulnerability index with the US Geological Survey's physically based coastal vulnerability index. The Coastal Vulnerability Index (CVI) consists of mean tidal range, coastal slope, rate of relative sea level rise, shoreline erosion and accretion rates, mean wave height, and geomorphology (erodability). Zhang *et al.* (2001, cited in Boruff*et al.*, 2005) developed an erosion potential index based on storm tides, wave energy, and storm duration of northeasters for much of the Atlantic Coast. In addition many of the social and economic characteristics that influence the vulnerability of individuals and communities along the coast are known at a conceptual level and have been integrated into a quantitatively derived Social Vulnerability Index(SoVI) designed for all counties in the US, except those in the Great Lakes, Alaska, and Hawaii. There are ethnic and racial disparities and economic differences between the regions. Economic differences are represented by average per capita income, density of commercial establishments, and earning density (a measure of county wealth derived from earnings). Boruff *et al.* (2005) used an analysis of variance (ANOVA) to test for regional differences in overall place vulnerability (PVI), social vulnerability (CSoVI), and physical vulnerability (CVI).

The U.S. Geological Survey has begun conducting scientific assessments of coastal vulnerability to potential future sea- and lake-level changes in 22 National Park Service sea and lakeshore units (Pendleton *et al*., 2010). This research approach combines the susceptibility of a coastal ecosystem to change with its natural ability to adapt to changing environmental conditions, and provides a measure of the system's potential vulnerability to the effects of sea- or lake-level change using the CVI methodology. The CVI describes a range of vulnerability (low to very high) indicating the potential susceptibility of a coastline to physical change as the sea or lake level changes. The index focuses on six variables that strongly influence coastal evolution: geomorphology, rate of historical shoreline change, regional coastal slope, relative sea-level change, mean significant wave height, and mean tidal range.

Coastal vulnerability was evaluated based on index values and ranked variables for all parks combined, as well as for the following geographic regions: the Atlantic coast, Great Lakes, Gulf of Alaska, Gulf of Mexico, oceanic islands, and Pacific coast. The variables defining the index are not independent or random; therefore, they do not contribute equally to the unweighted index. A principal component analysis (PCA) was used to reduce the dimensionality of the assessment data, illustrate the relationships among the variables, and identify the relative importance of each variable. This analysis was performed on the covariance matrix of the index, calculated such that five variables were held at the mean and one variable was allowed to change.

Tallis*et al.* (2011) assessed coastal vulnerability using the InVEST model and developed population and exposure index maps using a mixture of raster GIS, user input datasets of population, and seven bio-geophysical variables: geomorphology, relief, natural habitats (biotic and abiotic), net sea level change, wind exposure, wave exposure, and edge of the continental shelf depth contour (or other depth contour used to estimate surge potential).

As part of the Eurosion project in 2002, coastal erosion indicators were identified consisting of trends in coastal erosion (erosion rate), climate change (storm surge, sea level rise), and erosion hotspots. The Eurosion assessment also developed an information base at physical, technical, and socioeconomic levels.

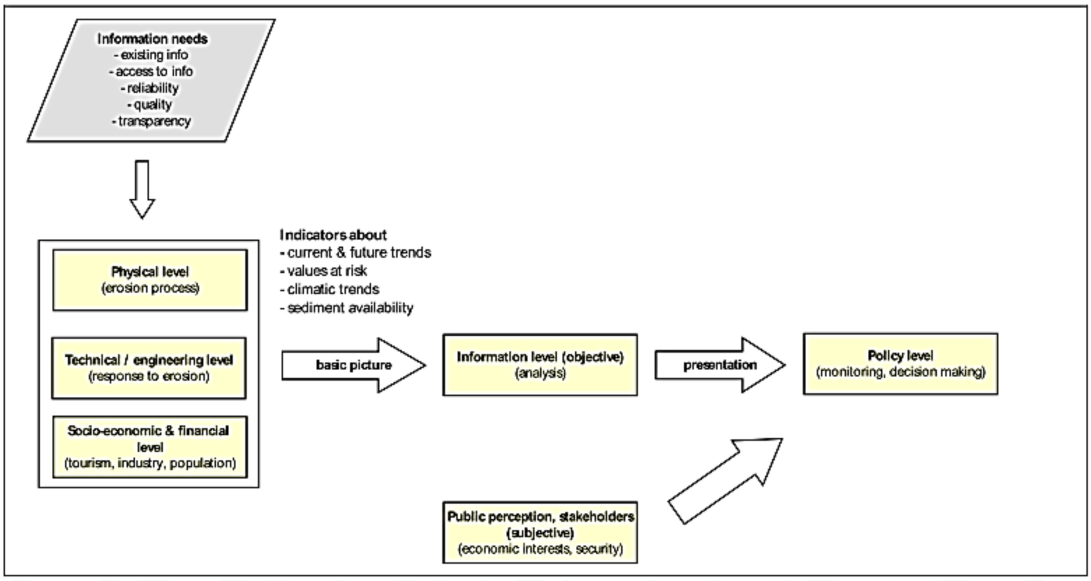


Figure 13 Eurosion assessment levels and indicator development
Source: Universitat Autonoma de Barcelona (2002)

The Eurosion project (2004)also developed three guidelines for better implementation of their recommendations: 1) coastal erosion concerns should be integrated into environmental assessments (both EIA and SEA), 2) hazards should be monitored and mapped, evaluated, and incorporated into planning and investment policies through a hazard assessment, 3) cost-benefit analysis of shoreline management measures provides a basis for making technical solutions financially viable; such analysis also helps identify external environmental costs that in turn may provide further incentives for managed realignment or simply "no action" instead of erosion control measures.

4.4 Forecasting long-term and large-scale coastal evolution

Both natural and human-induced changes in variables that govern coastal dynamics have a profound effect on the long-term and large-scale evolution of the coastal zone. Brommer and Bochev-Van der Burgh (2009) introduced a concept that addresses the components relevant to sustainable integrated coastal zone management. This study illustrated that quantifying sediment budgets in the coastal zone might improve our understanding of long-term (>100 yr) coastal evolution. In the context of integrated coastal management, the use of hydrological models that generate sediment loads and discharges for past and future time intervals can be important.

Literature Related to the Research Methodology

In summary, the literature related to the present research methodology is listed below:

- Rithpring (2002) identified factors of coastal zone change as both natural processes and anthropogenic activities.

- Geoindicators were defined by the International Union of Geological Sciences (IUGS) (Bush, 1999; Berger, 1996, 1997).The geoindicators of coastal zone impact assessment consist of erosion and accretion areas, erosion and accretion rates, beach slope, width of the beach, mangroves, coastal construction, strong wind-waves, river mouth location, beach morphology, and sediment type.

- GISTDA (2010, 2012) used satellite image analysis to evaluate the impact of coastal zone change along the coast of Thailand.

- Boak andTurner (2005) described the use of GIS and RS for spatiotemporal analysis of long-term and continuous data.

- Li *et al.* (2002) demonstrated mapping of a tidally coordinated shoreline using high-resolution satellite imagery.

- The DMCR (2012) investigated the impact of sea level rise on coastal zone change in the upper Gulf of Thailand and evaluated the economic losses (land value) using the market comparison approach.

- Bayani (2009) studied the impacts of coastal erosion on society and the economy, focusing onthe loss of beaches, loss of land, loss of livelihood, displacement of people, and destruction of property and infrastructure. The Economic Vulnerability index by IPCC (1997) was used in this research.

- The Eurosion project (2004) introduced the risk scoring approach in which a relative priority matrix is used as a guide for addressing various hazards. Designing such a matrix requires determining which factors are most critical to erosion and assigning weights accordingly.

- Himmelstoss (2009) described freely available software (DSAS) developed by USGS. The DSAS computes rate-of-change statistics for a time series of shoreline vector data. DSAS has been widely used for studying changing shorelines and evaluating the predictive accuracy of the rate of shoreline change.

- ESRI China (2011) has made available ModelBuilder/ArcGIS, which is an application in which models can be created, edited, and managed. This application is a built-in function in ArcGIS Desktop that strings sequences of geoprocessing tools together, creating and implementing a GIS model.

CHAPTER III

STUDY AREA

Location and Surroundings

The study area was located in Hat Chao Samran, Petchaburi Province, about 15 km from the provincial capital of Petchaburi in Hat Chao Samran Commune. Hat Chao Samran has a total area of 19,445 km^2 consisting of seven villages with a population of 4,532 (www.thaitambon.com). Hat Chao Samran is a straight sand beach oriented north-south and it is adjacent to Tambol Na Phan Sam, Amphoe Mueang, Laem Phak Bia, and Amphoe Ban Laem, Petchaburi Province tothe northand Tambol Nong Khanan and Amphoe Mueang, Petchaburi Province to the south.To the east it is bordered by the Gulf of Thailand and tothe west borders Tambol Nong Khanan, Tambol Nong Phlap, and Amphoe Mueang, Petchaburi province. The study area included 11 km along the coast and1 km landward, located in three Tambols: 1) Laem Phakbia, 2) Hat Chao Samran, and 3) Nong Khanan. The study location is between latitude 12°57′33.12″Nand longitude 100°02′20.73″E to latitude13°03′22.81″Nand longitude100°06′11.69″E.

Figure 14 Study area is located at Hat Chao Samran, Petchaburi Province
Source: Modify from GISTDA (2012)

Topography and Climate

Hat Chao Samran is an area with coastal wetlands. The beach is slightly sloped to the east toward the Gulf of Thailand and is a white sand beach suitable for swimming, which is a tourist attraction. The beach atmosphere is quiet and cool. There is abundance of marine shells, hermit crabs, and jellyfish. Accommodations are available and there is a convenience store nearby. There is a fishing village whose beaches are accreting sand, particularly in the early part of the beach. Hat Chao Samran has three seasons, similar to the rest of the country. Generally the weather is cool, remaining temperate because it is near the sea. Winter weather lasts for about 2–3 wk. The area has an average maximum temperature of 37.1 °C, average minimum temperature of 16.1 °C, average rainfall of 823 mm/yr, and an average humidity of 62–80% (Hat Chao Samran Municipal District, 2012).

Social Aspects

In 2013, Hat Chao Samran Commune had a population of 4,532, with 2,307 men and 2,225 women. There were 2,177 households and a population density of 240 people/km^2. Hat Chao Samran Commune is divided into 7 sub-communities: Ban Hat Chao Samran Nai, Ban Kok Plub, Ban Bang Thalu, Ban Smo Lok, Ban Bang Kula, and Ban Nong Ta Puk. Hat Chao Samran has 3 schools, one high school and two primary schools. Most of the residents are Buddhists. There are three temples, including Wat Hat Chao Samran, Wat Bang Thalu, and Wat Don Ban Mai. Most of the tradition and culture is related to competition among fishing boats, traditionally associated with religion. Since 2008, the main social problem has been drugs, followed by problem gambling and crime.

Economic Aspects

The residents of Hat Chao Samran work in the following sectors: agriculture and aquaculture (farming and fishing), industry, commerce, services, and tourism. According to data compiled from the Petchaburi Provincial Statistical Office (http://www.hadchaosamran.com) and from the strategic development plan by the Hat Chao Samran Municipal District in the same year, the total income in the district was 36.6 million baht, which represents approximately 20,824 baht/cap.

Agriculture and fisheries: Hat Chao Samran Commune has approximately 6,218 *rai* of paddy fields involving 299 households. Most of the higher elevation area is covered by irrigated paddy fields with good soil quality, which can be farmed year-round. The value of the yield is about 21.7 million baht/yr. Fishing is conducted along a coastal area of 6 km for small- to medium-sized fish. Additionally, there are some small coastal shrimp farms. In total, fishing supports 95 households.

Industry: Hat Chao Samran Commune has no large industrial factories, but there are three small family-operated rice mills.

Commerce and services: Commercial and retail services are limited. Some stores are located in communities along Highway No. 3177 and Hat Chao Samran Road.

Tourism: Tourism is a principal source of revenue, with 33,600 tourists/yr visiting the area, generating 13,440,000 baht/yr in revenue. Tourists spend about 400 baht per person.

Livestock: Commercial livestock in Hat Chao Samran Commune include cattle, poultry (chicken and ducks), and pigs.

Natural Resources and the Environment

Hat Chao Samran is an area where marine resources are abundant and is a beautiful place for recreation. Development along the coast has been rapid, bringing with it many natural resource and environmental challenges such as garbage, wastewater, coastal erosion, etc. Hat Chao Samran Commune is managed to prevent and find solutions for the variety of environmental problems that occur in both the short and long term. However, one of the main environmental issues in Hat Chao Samran is coastal erosion, with an erosion rate of about 3–4 m/yr (DMCR, 2012; GISTDA, 2012) Hat Chao Samran District coordinated with the Marine Department and budgeted approximately 220 million baht to build breakwaters to prevent erosion and to maintain the entire beach. Involvement of the public and the affected individuals or groups is important in addressing these challenges

.

CHAPTER IV

METHODOLOGY

This research was divided into two main approaches, as described in the sections below. Investigating a long-term perspective on coastal erosion at Hat Chao Samran, Petchaburi province is as following:

- The factors affecting coastal zone change: natural and man-made
- Impacts of coastal zone change: changes in the coastal zone, predictive modeling of future changes, and socioeconomic impacts
- Coastal risk mapping: defining the sensitivity index and risk mapping

Developing spatial modeling consists of integration of spatial modeling, including 1) preparation of the input data, 2) creating the spatial model, and 3) data analysis

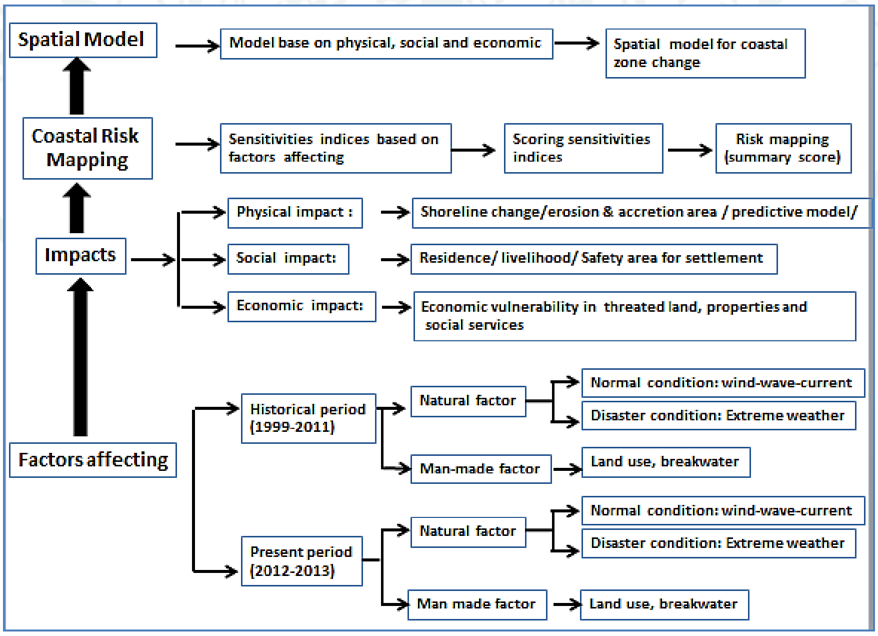


Figure 15 Methodology flow chart for developing a spatial model for predicting long-term coastal zone changes.

Factors Affecting Coastal Erosion at Hat Chao Samran

First, we focused on past and present situation and future trends in coastal zone changes. The factors affecting the coastal area, both natural and anthropogenic, were investigated. Natural factors consist of wind-waves, tidal behavior, currents, beach slope, sediment characteristics, extreme weather events, and anthropogenic factors such as land use in the area (Masele and Mayungal, 2000;Rithpring, 2002; Pilkey and Yong, 2009; Klemas,2012;Park and Edge, 2011).

1. Natural factors

The historical natural factors affecting coastal erosion at Hat Chao Samran were studied using historical data for three main parameters: wind-waves, current pattern, and extreme weather. These factors were analyzed and statistically summarized, presented in Table 1.

Table 1 Historical natural data set analysis.

Factors	Source of data set	Tool/Equipment	Analysis approach
1. Natural			
1.1 Wave-wind Climate	-Buoy data network (1993-2006)	Microsoft Excel	Statistical analysis (average, min, max)
1.2 Current pattern	-Buoy data network (1993-2006)	Microsoft Excel	Statistical analysis (average, min, max)
1.3 Extreme weather	-Thai Meteorological report (1951-2006)	Microsoft Word	Graphic/chart

The present situation in the study area was also investigated. Factors affecting coastal zone change and impacts were evaluated by collecting field data. The collection period was divided into two periods based on the monsoons, specifically, during the southwest (SW) and northeast (NE) monsoon seasons. The methods are described in Table 5 and the data collection area is shown in Figure 16. Sampling equipment is shown in Figure 17.

Table 2 Present natural data collected from the field surveys and remote sensors.

Factors	Source of data set (NE and SW monsoon)	Tool/Equipment	Analysis approach
Natural factors			
1.1 Wave characteristic	-Coastal radar network of GISTDA from 2012-2013	-ArcGIS 10.1 -Microsoft Excel	Average, Min-Max
1.2 Current pattern	-Coastal radar network of GISTDA from 2012-2013 -Drifter with GPS	-ArcGIS 10.1 -Microsoft Excel	Speed and direction analysis
1.3 Wind data	-Wind speed and direction both SW and NE monsoon	-Wind sensor	Speed and direction analysis
1.4 Tide behavior	- The report of Hydrological Department, Royal Thai Navy	-Report	Mean Sea Level analysis
1.5 Beach profile	- Beach measurement	- DGPS	Transect line
1.6 Sediment characteristic	- Sediment size	-Grab sample -GPS	Laboratory analysis
1.7 Extreme weather	-Data collection from the report of Thai Meteorological Department in 2012	-Report	Number and passage of typhoon

2. Anthropogenic factors

Changes in land over the past 15 yr were determined using LANDSAT images and the present situation in the study area was also evaluated. Object-based analysis techniques using eCognition Developer were introduced to analyze long-term human activities. The image classification process was carried out by developing a rule set and classification thresholds, followed by supervised classification. The images were classified into six land use types: 1) bare land, 2) urban areas and buildings, 3) aquaculture and salt flats, 4) mangroves, 5) agriculture and rice fields, and 6) water.

The classified images were checked for accuracy using the data from the ground truth survey and then the final classification map was developed using post-classification. The overall land use classification process is shown in Figure 16. In addition, this study also found structure of breakwater for protection the beach in study area.

Table 3 Historical anthropogenic data set analysis.

Factors	Source of data set	Tool/Equipment	Analysis approach
Man-made			
Land use change detection	-LANDSAT Satellite images with resolution 30 m from 1992 to 2011	-eCognition Developer	-Object based analysis
Breakwater	-QUICKBIRD satellite image in 2009 -THAICHOTE 2012	-ArcGIS 10.1	-Data view

Table 4 Present anthropogenic data, physical and socio-economic impact collected from the field surveys.

Factors	Source of data set (NE and SW monsoon)	Tool/Equipment	Analysis approach
1.Man-made			
1.1 Land use change	- Ground Control Point (GCP) collection from field survey - THAICHOTE (2.5 m/15 m) in 2012	- GPS and digital camera -ArcGIS 10.1	-Post classification with ArcGIS
1.2 Breakwater	-THAICHOTE satellite image in 2012	-ArcGIS 10.1	-Data view
2. Physical impact			

Table 4 (Continued)

2.1 Shoreline change	- Ground Control Point (GCP) collection from field survey	- DGPS - Digital camera	- Tide adjustment of shoreline vectors
2.2 Beach profile	- Beach slope collection from field survey	-DGPS -Digital camera -Beach profile meter	Graphical presentation
3.Socio-Economic impact			
3.1 Land use change	- Key Informants Interview - Report of Hat Chao Samran municipal district	-Microsoft excel - Questionnaire	- Statistical analysis
3.2 Changing of residence	- Key Informants Interview - Landsat 30 m. and THAICHOTE (2.5 m/15 m) in 2012	-Microsoft excel - Questionnaire -ArcGIS 10.1	- Statistical analysis
3.3 Properties values	- Data from Treasury Department	-Microsoft excel	- Statistical analysis

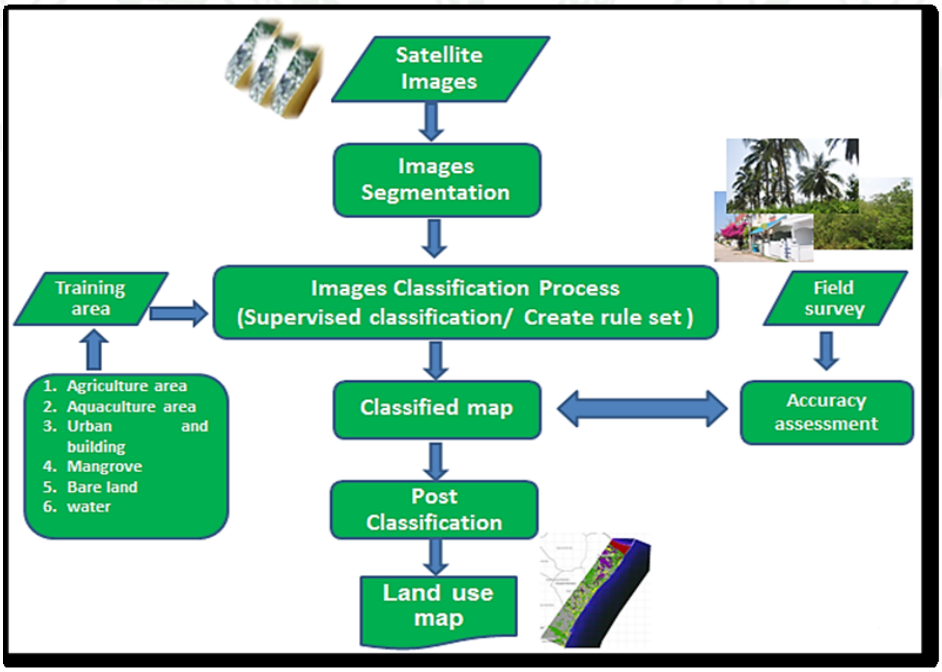


Figure 16 Analysis of coastal land use change using satellite imagery

Figure 17 Field data collection in the sea and land areas

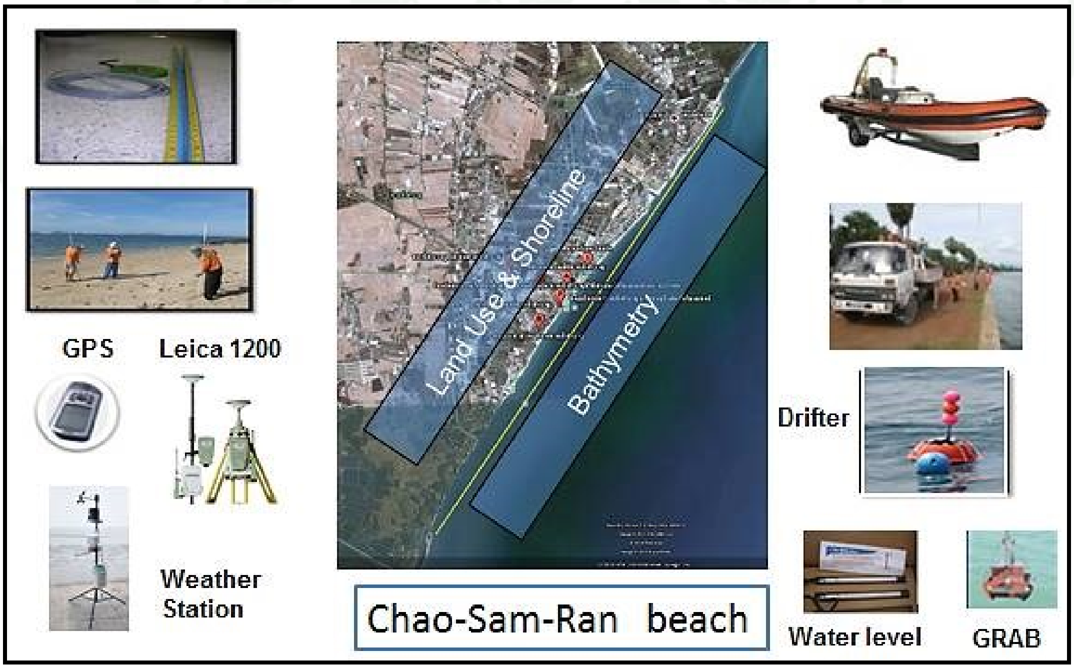


Figure 18 Sampling equipment for field data collection

Impacts of Coastal Zone Changes at Hat Chao Samran

In addition to field data collection, analyses of physical impact in the coastal zone, prediction of shoreline changes, and assessment of socioeconomic impact were conducted.

1. Physical impact in the coastal zone

Coastal erosion and accretion areas and rates of erosion were investigated through spatial data analysis. LANDSAT satellite images from1999–2011were used as the input data. The satellite images were georeferenced before extracting the shoreline. Object-based analysis using eCognition Developer and spatial analysis using ArcGIS 10.1 was used to extract a time series of shoreline vectors, because the shoreline is an important and dynamic feature. The accuracy of shoreline mapping is dependent on obtaining a tidally coordinated shoreline (Li *et al.*, 2002), thus the effect of the tides need to be taken into account. Changes in each shoreline position were calculated. Negative changes in the time series of shoreline vectors represent erosional areas. In contrast, positive changes in the shoreline position represent accretion areas. Identification of coastal erosion and accretion areas is shown in Figure 19.

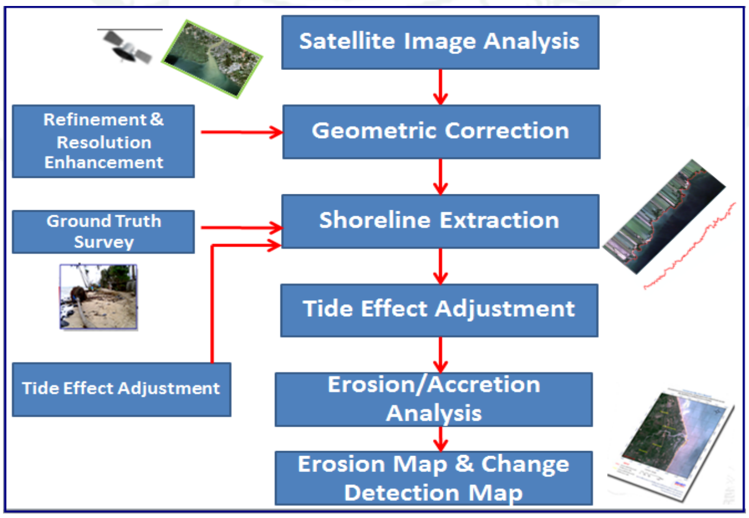


Figure 19 Shoreline vector extraction and erosion and accretion mapping using satellite images

2. Shoreline change predictive model

The extracted shoreline vectors from LANDSAT satellite images from 1999–2011were used to identify coastal boundaries and a time series of shorelines. The erosion rate was also computed using the baseline measurement method to calculate rate-of-change statistics from the time series of shorelines using DSAS (Himmelstoss, 2009). Each shoreline vector represents a specific point in time and is assigned a date in the shoreline feature-class attribute table. The measurement transects cast by DSAS from the baseline intersect the shoreline vectors. The points of intersection provide location and time information used to calculate rates of change. The distances from the baseline to each intersection point along the transects are used to compute the selected statistics. The end point rate (EPR) is a statistical method appropriate for use with the shoreline vectors, shown below:

$$\text{End Point Rate} = \frac{\text{Distance in meters}}{\text{Time between oldest and most recent shoreline}} \quad (1)$$

The equation used to predict shoreline changes was as follows:

$$\text{Shoreline Position} = (\text{slope} * \text{the shoreline date}) + \text{Intercept} \quad (2)$$

Prediction of shoreline changes was conducted for three different time periods, the short term (5 yr), medium term (10 yr), and long term (20 yr).

3. Socioeconomic impacts

The impacts of coastal erosion on the economy and social amenities of the study area were assessed through socioeconomic evaluation together with an overlay technique using ArcGIS (DMCR, 2012).

3.1 Social impact assessment of the study area

Social impacts were focused on analysis of settlement risks due to coastal erosion in communities. Coastal regions are subject to the action of ocean waves and storms and naturally experience erosion and inundation over various temporal and spatial scales, which can also threaten human populations and activities. When estimating the exposure of coastline communities to erosion, it is important to consider changes in the populations and migration patterns subject to these hazards. For this assessment, we used historical data for changes in coastal land use and population migration patterns. The population was derived from census data. Changes in land use and infrastructure were determined through analysis of satellite images. In addition, changes in residence or migration were investigated by interviewing key individuals such as community leaders, tourists, local people and local governmental agencies. The sample was performed by Yamane (1967) at a confidence level of 90%. All relevant data including changes in land use and population migration patterns, and shoreline change rate were overlain using ArcGIS to determine the risk of resettlement of communities due to coastal erosion in study area. The overall risk analysis method is shown in Figure 20.

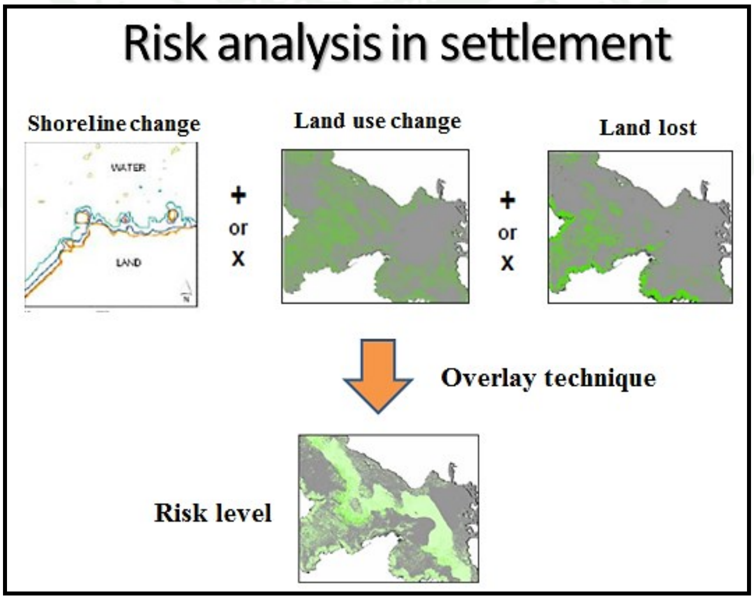


Figure 20 Risk analysis for resettlement of communities

3.2 Assessment of economic losses in the study area

Assessment of economic losses was conducted by measuring economic vulnerability (EV) as defined by the IPCC (1997) cited in Bayani (2009) and the use of land value appraisals for the area determined through the market comparison approach (DMCR, 2012). EV is computed based on the value of threatened buildings and infrastructure (roads, factories), the value of threatened land in the affected area and the value of social services from threatened beaches (recreational services).

$$EV = TVBS + TVL + TVS \qquad (3)$$

Where:

EV	=	Economic vulnerability
TVBS	=	the total value of threatened buildings and infrastructures
TVL	=	the total value of threatened lands
TVS	=	the value of social services from threatened beaches

3.3 Value of threatened buildings and structures

Data for property values (buildings and infrastructure) and land values were obtained from the Department of the Treasury and local governmental agencies. In addition, if there was enough activity in the market, land values could be directly determined or assessed against comparable properties on the market. We collected data for an area approximately 300m inward of the eroded coastline.

To calculate the current value of all buildings and structures threatened by shoreline erosion, the following equation was used:

$$\text{TVBS} = \sum_{i=1}^{n} VB_i + \sum_{j=1}^{m} VS_j \qquad (4)$$

Where;

VB = value of building I; n is the total number of buildings at risk.

VS = value of structure j; m is the total number of structures at risk.

3.4 Value of threatened lands

To determine the value of threatened lands, current market prices were based on the average prices quoted by real estate brokers (http://www.teedin108.com/land/view/361370 and http://phetchaburi.homeland4sale.com). The market value was estimated at the current land price per square meter. The current value of all lands (TVL) threatened by shoreline erosion was computed using the following equation:

$$TVL = \text{Land market value per sq. m} * \text{total land area at risk} \qquad (5)$$

In addition, the future annual rate of change of land prices was also calculated using statistical data from the Treasury Department (http://property.treasury.go.th/pvmwebsite).

3.5 Value of social services from threatened beaches

It was nevertheless important to still include the value of the beaches in the analysis considering the benefits and services that they provided as well as the potential impacts of some coastal erosion adaptation options on them. From the site visits that the researcher conducted, the uses of the beach along Chao Samran beach was identified for recreation (e.g. picnics, jogging and swimming) by nearby residents and resorts. Thus, to estimate the recreational value of the beaches in Chao Samran beach, the study applied the simple benefit-transfer method. The benefit-transfer method is a procedure used in cost-benefit analysis (CBA) where previously estimated shadow prices or values are just adopted and incorporated into the cost-benefit calculations. In this study, the recreational values of beaches estimated by Colgan and Lake (1992) cited in Bayani (2009), was used. The values were translated into local currency using the shadow exchange rate and further adjustments were made based on the prevailing recreational use of the beaches in Chao Samran beach. Details of the computations are as below;

Annual Recreational Value of Beaches = E*S*V*P (6)

Where

E = Expense per person per day (USD)

S = Shadow Exchange Rate (SER)

V = Percent of visitor utilized the beach for recreational purpose

P = The respondents visited the beaches an average of visited days per week for about x hours per day

Coastal Risk Mapping

Understanding of coastal erosion in the study area by the coastal risk mapping helps to support coastal management more effectively. The first step was to analyze the sensitivity index of erosion. Then the risk map was done using GIS techniques. Details are as below.

1. Coastal erosion sensitivity index

The purpose of this step was to combine different criteria form the geoindicators of coastal erosion risk developed by IUGS (Bush,1999; Berger, 1996,1997) in order to map the risk area along Hat Chao Samran.

Table 5 Categories of input data.

Type of index	Type of feature
Geo-indicators	
- shoreline erosion –accretion rate(1999-2012)	- Line
- beach slope	- Line
- coastal construction (breakwater)	- Polygon
- wind-wave	- Point
- river mouth location	- Point
- sediment type	- Point
- Land use (1999-2012)	- Polygon

To analyze correlations among land use types and changes in the coastal area, Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR) were used for spatial regression. OLS and GWR allow the modeling of processes that vary over space. OLS provides a global model and was the initial process applied, while GWR provides a local model by fitting a regression equation to every feature in the dataset. GWR produced a set of local parameter estimates for each relationship, which were mapped to produce a parameter surface across the study region (Charton *et al.*, 2002).

Modeling of spatial relationships is considered to be a local regression model and is given by:

$$Y_i = a_0(U_i, V_i) + \sum_k a_k (U_i, V_i) X_{ik} + \varepsilon_i \quad (7)$$

where (U_i,V_i) are the coordinates of the i^{th} point in space and $a_k(U_i,V_i)$ represents the continuous function $a_k(U,V)$ at point i.

This process resulted in a continuous surface of parameter values and measurements of this surface were taken at specific points to determine the spatial variability of the surface. In determining the spatial relationships, an observation was weighted based on its proximity to point i, so that the data from observations close to i were weighted more heavily than data from observations farther away. It was assumed that observed data near point i have a greater influence on$a_k(U_i, V_i)$ than data located further from i.

The regression analysis terms and concepts are given in ESRI (2013), which states that reliable statistics for examining and estimating linear relationships are provided by the regression equation below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots\ldots\ldots + \beta_n X_n + \varepsilon \quad (8)$$

Where Y = Dependent variable

X_i = Independent/Explanatory variables

β_i = Regression coefficients / β_0 = Regression intercept

ε = Residuals / random error term

The analysis of spatial regression between coastal area change and the type of land use from 1999 to 2011 was done using the spatial statistical technique in Eq.8. Thus, we utilized the following variables:

Dependent variables: Y_1 = Erosion area and Y_2 = Accretion area

Independent variables: X_1 = Mangrove area

X_2 = Aquaculture and salt flat area

X_3 = Agriculture and rice field area

X_4 = Bare land

X_5 = Urban and building area

Oceanographic buoy data (1993–2006), meteorological data (1999–2011), and field data (2012–2013) were statistically evaluated and categorized by criteria scores. The criteria scores followed the risk scoring approach used by the Eurosion project (2004). The individual criteria were analyzed and combined to establish risk categories for coastal erosion. A scoring system can be used for this analysis as shown below:

$$\text{Total Score} = (\text{Frequency} + \text{Area Impact}) \times \text{Potential Damage Magnitude} \quad (9)$$

Overall risk was then determined using the established criteria for the period 1999–2011.

2. Risk mapping

Using a GIS, environmental sensitivity mapping was conducted to identify areas at risk by adding the scores to create summary scores for each location in the area. These summary scores were used to develop a summary risk area map.

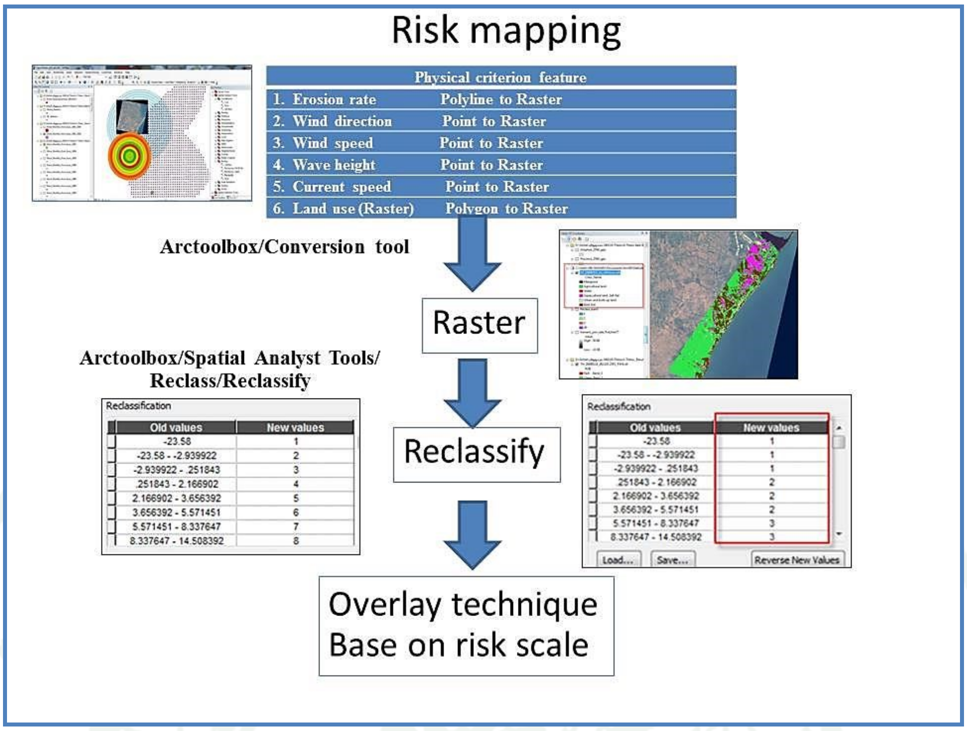


Figure 21 Risk mapping procedure

Integration of Spatial Modeling

The coastal zone is a continually changing environment, not only from year to year, but also by the month, day, and even hour. Due to this constant state of change, mapping and analysis can be especially challenging for the user attempting to compare various GIS data layers from different sources. The process architecture used is shown in Figure 22.

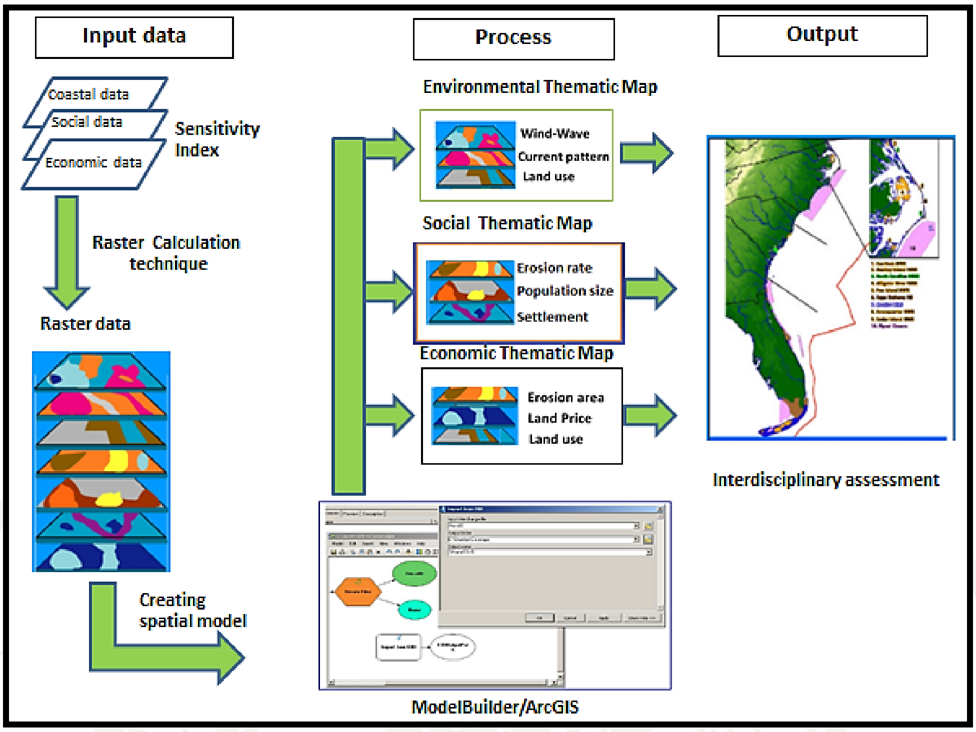


Figure 22 Spatial modeling architecture

1. Preparation of input data

The sensitivity indices were grouped and used as input data for the spatial model. The input data were categorized into three groups as shown in Tables 6 and 7.

Table 6 Categories of input data.

Groups	Input data details
1.Physical indexes	Erosion& accretion rate was selected to be input data. -High risk: erosion rate > 5 m/yr. -Medium risk: erosion rate 1-5 m/yr. -Low risk: erosion rate <1 m/yr. or accretion rate > 10 m/yr.
2.Social indexes	Safe zone for residential, community area and land use were selected to be input data. -High risk: land use 0-50 m away from the shore -Medium risk: land use 50-100 m away from the shore -Low risk: land use >100 m away from the shore
3.Economic indexes	Loss of land (erosion) and damaged building in the past 12 years were selected to be input data. -High risk: damage> 100 million baht -Medium risk: damage 50- 100 million baht -Low risk: damage < 50 million baht

Table 7 Categories of risk.

Risk level	Details
High risk	- erosion rate > 5 m/yr. - land use 0-50 m away from the shore - damage> 100 million baht
Medium risk	- erosion rate 1-5 m/yr - land use 50-100 m away from the shore - damage 50- 100 million baht
Low risk	- erosion rate <1 m/yr. - land use > 100 m away from the shore - damage < 50 million baht

2. Developing the spatial model

ModelBuilder in ArcGIS 10.1 was used as geo-processing tools to create a spatial model for this study (Chaaban *et al.*, n.d.; Espey, n.d; Scleupner, n.d; Rocha *et al.*, 2007). First, a new toolbox was created as a folder or Geodatabase. Second, a Geodatabase feature class was created and used to append coverage features in later steps. All of the model elements and input data were input into the new model, and spatial analysis and running of the model was carried out using the toolbar.

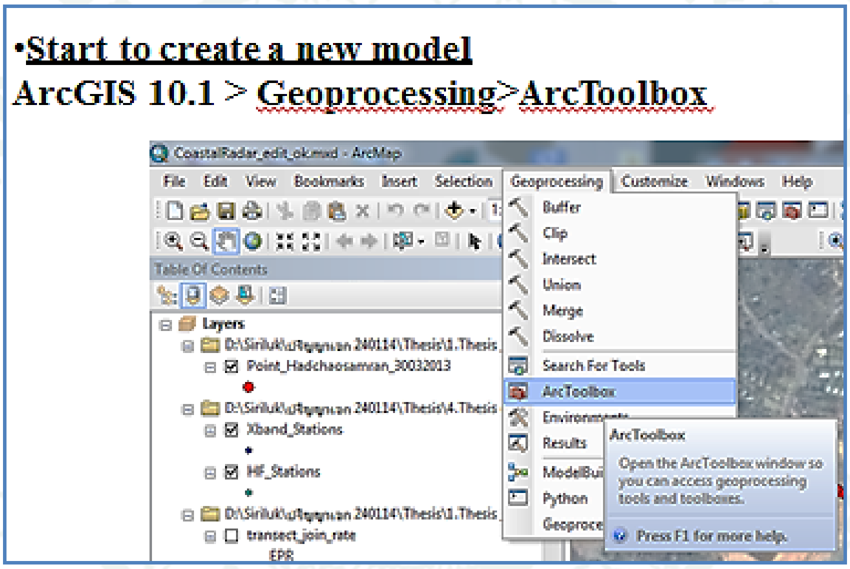


Figure 23 Creating the spatial model using ModelBuilder in ArcGIS

3. Data analysis

Data analysis consisted of integrating the risk scoring approach and spatial analysis. The sensitivity indices were defined based on vulnerable physical, social, and economic features within hazardous spatial units (Abuodha and Woodroffe, 2006; Thieler and Hammer-Klos, 1999; Shaw *et al.*, 1998; Xhardé, 2007; Boruff *et al.*, 2005). Weighted risks were incorporated for these various aspects. The spatial data were analyzed based on the developed criteria such as the lowest risk, highest land prices, etc. The overlay process is a key step in bringing together existing data from a variety of maps to analyze the data for decision-making. Maps were overlain using coupling points (x, y) and attribute data were created after overlaying. Arithmetic processing (e.g., addition, subtraction, multiplication, division) or logical processing (e.g., AND, OR, XOR, etc.) were conducted as part of the overlay process. Formatting of the overlain data involved buffering, clipping, and map merging. Running the model is the final step in data analysis. Each process is connected by linking the output of one process to the input of another using the connection tool.

In ArcGIS, modeling can be done either through the ModelBuilder graphical user interface (GUI) or through code, using Python. To keep our terms clear, we'll refer to anything built in ModelBuilder as a "model" and anything built through Python as a "script". However, it's important to remember that both things are doing modeling.

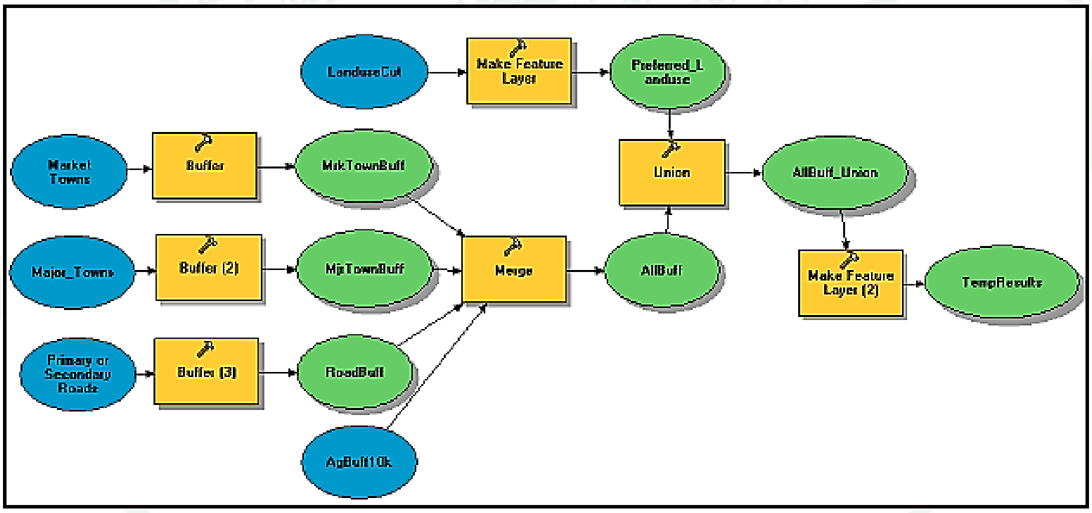


Figure 24 Running the model for each linked process and output
Source: ESRI China (2011)

CHAPTER V

RESULTS AND DISCUSSION

Factors Affecting to Coastal Zone Change at Hat Chao Samran, Petchaburi Province

Factors affecting the coastal areas at Hat Chao Samran covered the period from the past and the present, between1999-2013.During this time, the analysis focused on the factors that caused by natural factors and man-made activities. These factors affecting analyzed base on Geoindicators and the factors that influence the Hat Chao Samran, in summary include strong wind-wave, current, sediment type, beach slope and extreme weather. Detailed results are the following.

1. Historical factors

Historical factors analyzed in the period between1999-2011.Main factors that influence the Hat Chao Samran in this period, consisted of strong wind-wave, current and extreme weather. The analytical results are summarized as follows.

1.1 Historical natural factors (1999-2011)

Wind-waves and currents

Historical data for wind-waves and currents during 1993–2006 from the SEAWATCH project (Appendix 1) were analyzed. Changes in the wind-waves and currents in the Gulf of Thailand were dominated by changes in monsoon weather, particularly during the second inter-monsoon and NE monsoon (Table 8).

Table 8 Monsoon periods in the Gulf of Thailand.

Monsoon	Period	Wind characteristic
NE monsoon	Nov –Jan	NE , N, E wind,
1st inter-monsoon	Feb-Apr	S, SE wind
SW monsoon	May-Aug	SW, S wind
2nd inter-monsoon	Sep-Oct	SW, W, NW, S wind

Source: Snidvongs (1998).

The highest waves were found during the NE monsoon (0.1–3 m),followed by the second inter-monsoon (0.1–2.0 m), SW monsoon (0.1–1.7 m),and first inter-monsoon (0.1–1.3 m).The maximum wind speed was observed during the second inter-monsoon (0–25m/s), followed by the NE monsoon (0–21 m/s), SW monsoon (0–20 m/s),and the first inter-monsoon (0–13m/s).

Table 9 Historical wind-wave sand currents during 1993–2006.

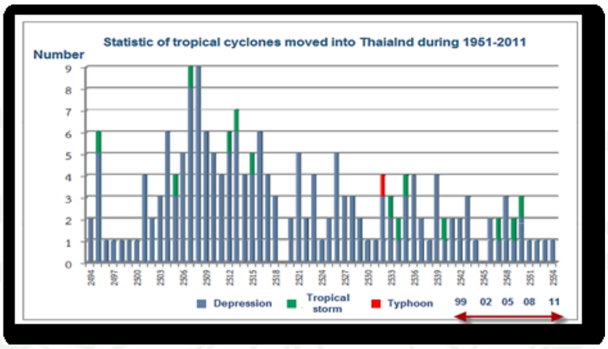
Parameters	NE monsoon (Nov-Jan)	1st transition period (Feb-Apr)	SW monsoon (May-Aug)	2nd transition period (Sep-Oct)
Wave height (m)	0.1-3.0	0.1-1.3	0.1-1.7	0.1-2.0
Wind speed (m/s)	0-21	0-13	0-20	0-25
Current speed (cm/s)	77.0-77.9	29.8-63.8	10.4-39.1	56.3-100.0

*Wind speed from oceanographic buoy (SEAWATCH buoy)

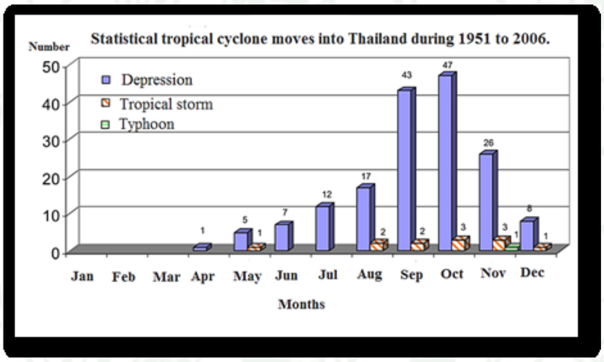
The maximum current speed was observed during the second inter-monsoon (56.3–100.0cm/s), followed by the NE monsoon (77.0–77.9cm/s), first inter-monsoon (29.8–63.8 cm /s), and SW monsoon (10.4–39.1cm/s).

Extreme weather

Another natural factor that is very important for erosion is extreme weather. Historical data for tropical cyclones during 1951–2006(Department of Meteorology, 2007) recorded the number of storms during October–November each year that came through the Gulf of Thailand, typically12–18over the past60 yr. Storms tended to move from the South China Sea past Cape Ca Mau, Vietnam toward Phetchaburi and Prachuap Khiri Khan.



-Fig.25a-



-Fig. 25b-

Figure 25 Historical statistics for tropical cyclones over the past 60 yr that moved into the Gulf of Thailand (a); most of the tropical cyclones occurred in September–October during the second inter-monsoon (b)

Source: Meteorological department (2007)

There were18 storms in October and 12 storms in November that moved into the Gulf of Thailand and passed near Petchaburi and Prachuapkhirikhan Provinces (Figures 26–27). Because Hat Chao Samran is a long, straight beach, it is directly influenced by monsoons. Thus, monsoon weather and associated storms are very important influences on coastal zone changes in this area.

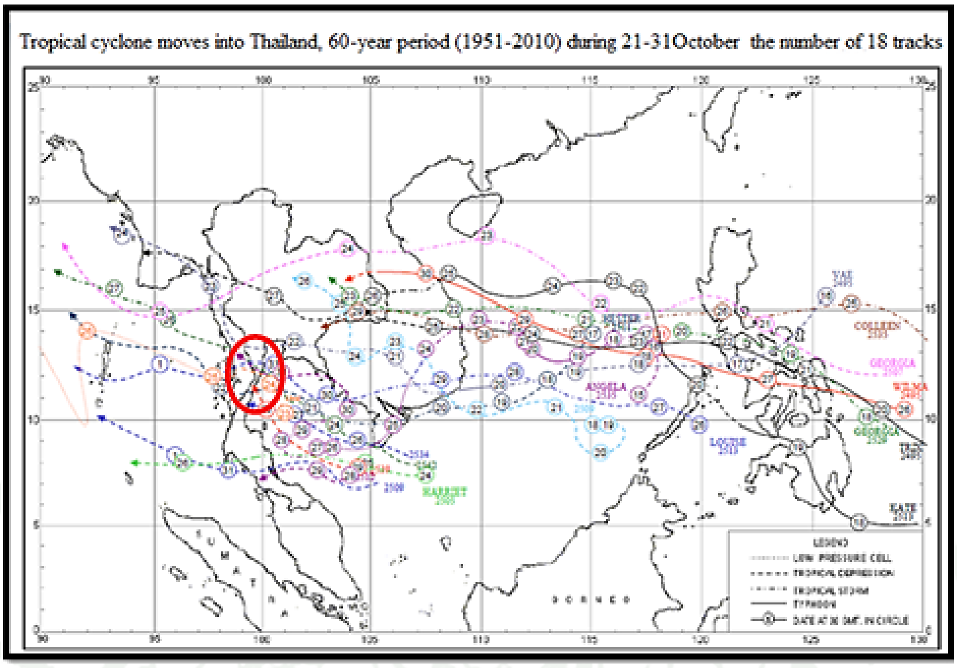


Figure 26 Tracks of storms that moved into the Gulf of Thailand and passed near the Petchaburi and Prachuapkhirikhan Provinces

Source: Meteorological department (2007)

1.2 Historical anthropogenic factors

Historical factors analysis of human activities in the area focused on the factors affecting to the coast during 1999-2011, such as land use and breakwater.

Land use changes (1999-2011):

Using LANDSAT satellite images from1999 to 2011, land use types were classified into five categories: mangroves, agriculture and rice fields, aquaculture and salt flats, urban and building areas, and bare land (Figure 29). During this time period, most of the coastal area was used for agriculture, particularly rice cultivation, reaching a maximum in 2000 and still covering large areas. The second largest area was used for aquaculture and salt flats, with the area increasing from 1999 to 2008 and then decreasing from 2009 to 2011. The next largest area was used for urban areas and developed land, which continuously increased after 1999. Changes in the amount of bare land were related to changes in aquaculture area. The least area was occupied by mangroves, which changed less than other types of areas.

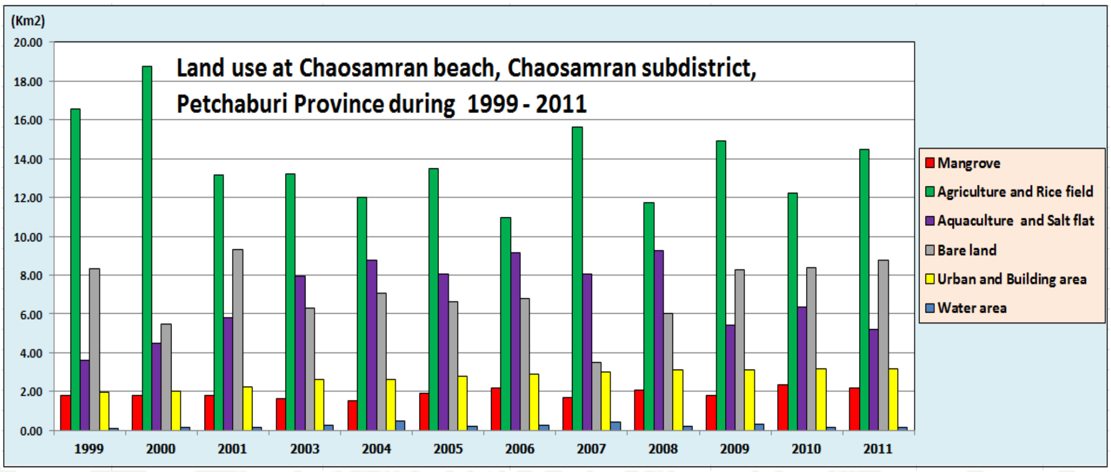


Figure 27 Land utilization at Hat Chao Samran during 12 years between 1999 and 2011showing agriculture and rice fields (green), aquaculture (purple), bare land (grey), urban and developed areas (yellow), and mangroves (red)

From figure 27 showed the variation of all land use types in study area during 1999-2011. The land use changes are detailed below.

Mangrove areas totally increased from 5.52% to 6.73%. However, there were small conversions from agricultural, aquaculture, residential, and water areas.

Agriculture areas totally increased from 28.32% to 31.28%, and planted area becoming smaller and more scattered. The greatest changes were from aquaculture, urban, bare land, and water areas, respectively.

Aquaculture and salt flats entirely decreased from 10.97% to 17.09% and this area converted from agriculture, bare land, and mangrove areas, respectively.

Urban areas and developed land continually increased from 6.03% in 1999 to 9.72% in 2011, with conversions from agricultural areas and bare land.

Bare land entirely increased from 38.54% to 48.77%.

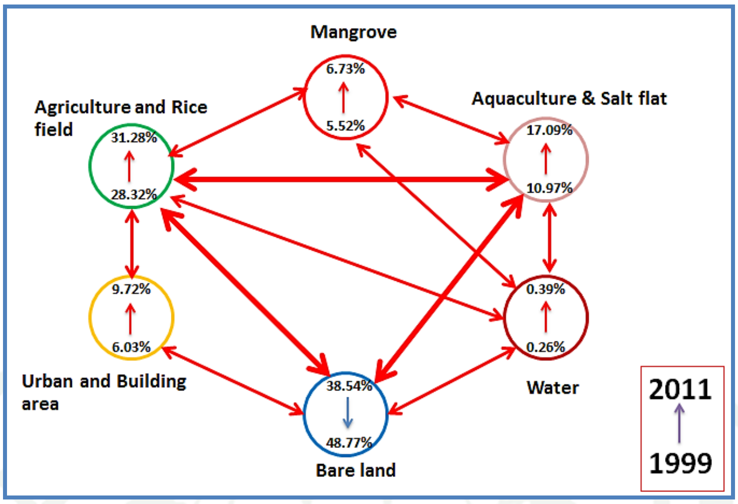


Figure 28 Changes in land use during 1999–2011 at Hat Chao Samran, Petchaburi Province

Moreover, land use analysis identified clear increases inland for aquaculture and salt flats, agriculture, urban areas, and mangroves with increases of 6.12, 4.94, 3.69, and 1.21%, respectively. Bare land decreased by 10.23% (Figure 29).

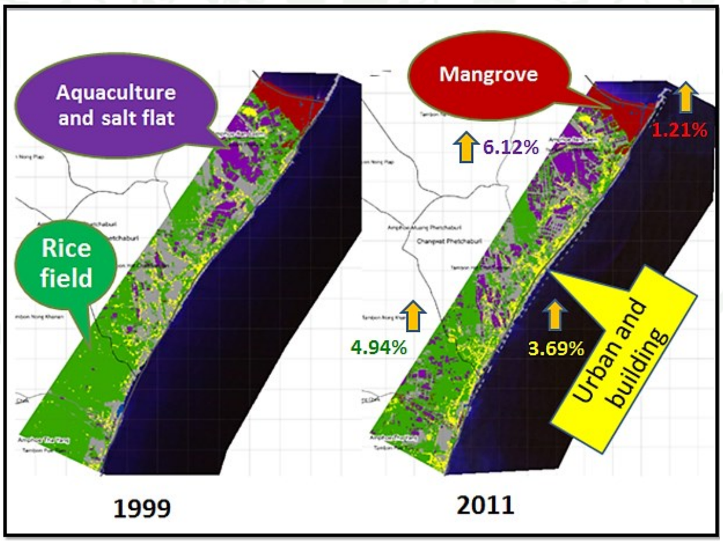


Figure 29 Increasing in urban areas (yellow) along Hat Chao Samran between 1999 and 2011

Breakwater (2007-2008):

According to the Hat Chao Samran District information and viewing with LANDSAT and THAICHOTE satellite images found that the changes in the coastal area could be due to anthropogenic activities such as the protection for the beach that was built in 2007–2008.Characteristics of the breakwaters were built of stone, with a total of about 27 stacks and placed parallel to the Hat Chao Samran beach, a distance of about 7 km. The construction of the breakwater caused a marked sediment imbalance in this area, especially after 2009. The deposition of sediments will increase on the front and erosion will increase on the back side of the breakwater (Satumanatpan, 2012; Taveira-Pinto *et al.,* 2011).

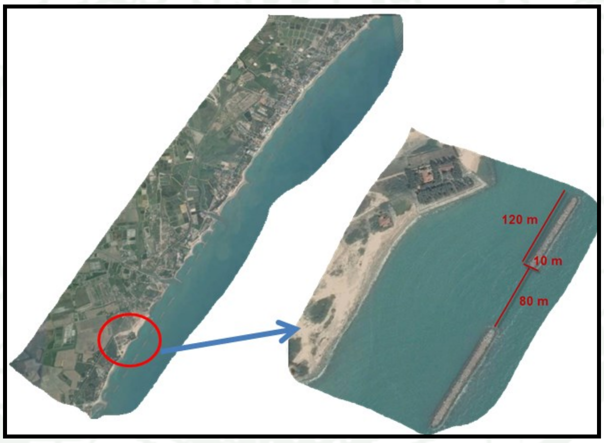


Figure 30 Characteristics of Breakwaters placed in parallel to the coast of Hat Chao Samran.
Source: THAICHOTE (2012)

2. Present factors

Present factors analysis was done to investigate and compare the factors affecting to the coast during the transition period from past to present by collecting data in the field during the NE and SW monsoon in 2013. Present natural factors include strong wind-wave, current, sediment type, beach slope and extreme weather. Present anthropogenic factors consist of land use and breakwater. The analytical results are summarized as follows.

2.1 Present natural factors (2012-2013)

Analysis of present natural factors includes strong wind-wave, current, sediment type, beach slope and extreme weather. All data were collected using several tools, such as coastal radar network, wind sensor, grab sample, GPS, digital camera and beach profile meter. Details of the analysis are as follows.

Wind wave and current

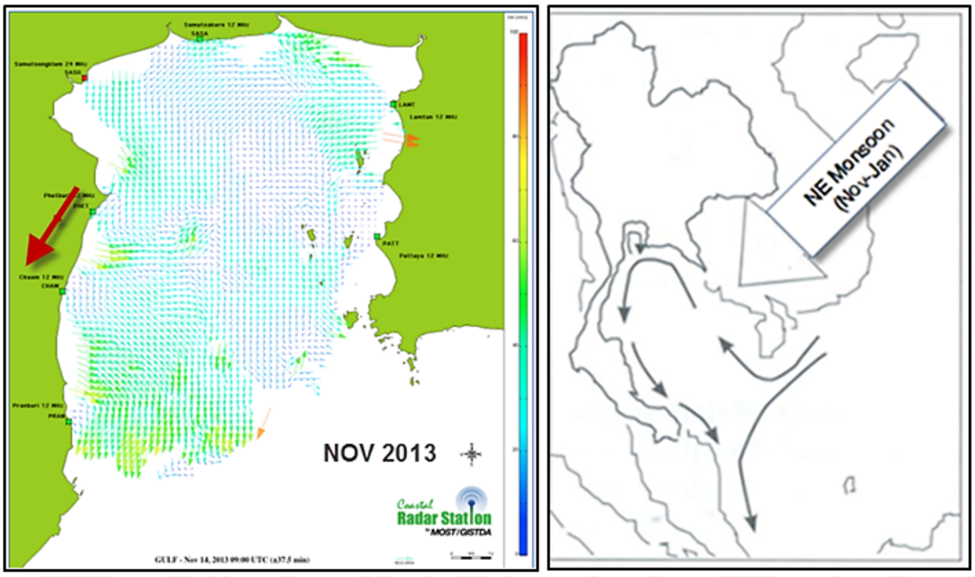
Data for typical waves and currents were collected for a period of one year (Jan-Dec 13) from a coastal radar sensor along the coast of Petchaburi. The beach profile, tides, and sediment data were sampled in the field during two monsoon periods, the SW (Apr 1-5, 2013) and NE (Nov 28-30, 2013) monsoon. Other essential weather data were also gathered in the field or from reports of Meteorological Department or http://www.accuweather.com/. Wind data for Petchaburi Province was correlated with that from the Agrometeorological station at RatchaburiProvince (http://www.aws.observation.tmd.go.th/web/aws/aws_windroses.asp).

Table 10 Wind-wave sand currents from coastal radar network in 2013.

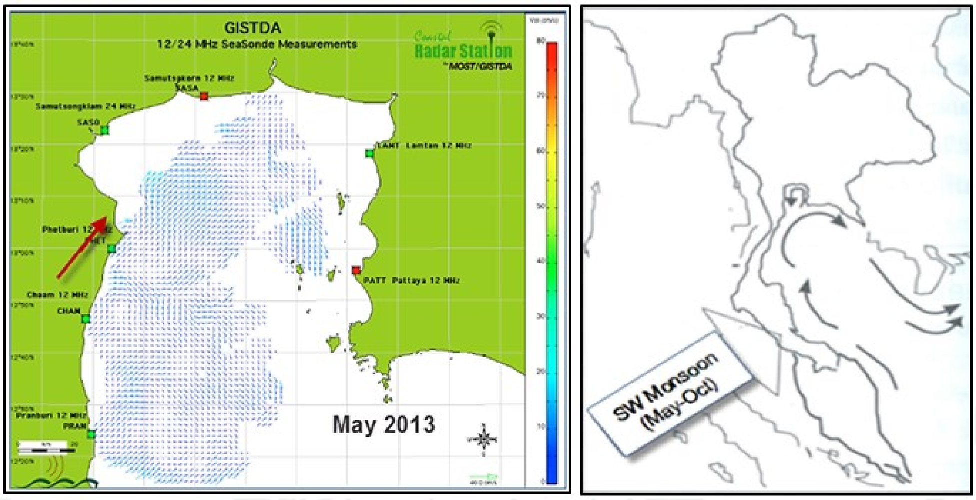
Parameters	NE monsoon (Nov-Jan)	1st transition period (Feb-Apr)	SW monsoon (May-Aug)	2nd transition period (Sep-Oct)
Wave height (m)	0.15-5.0	0.15-4.33	0.1-4.12	0.1-3.0
Wind speed* (m/s)	1.57-2.52	2.8-3.36	2.7-3.64	2.9
Current speed (cm/s)	0.01-80.0	0.02-100.0	0.08-14.52	0.31-22.94

*Wind speed from Agrometeorological station

Circulation pattern data from the radar network showed that the flow pattern is consistent with the Department of Fisheries (2010) data showing anti-clockwise flow during the NE monsoon and clockwise flow during the SW monsoon (Figure31).



-Fig 31a-



-Fig 31b-

Figure 31 Circulation patterns in the Gulf of Thailand, using data from the coastal radar network of GISTDA (2013) (left) and circulation patterns from the Department of Fisheries (2010) (right) showing circulation in NE monsoon (a) and SW monsoon (b).

Source: Coastal radar network (2013) and Department of Fisheries (2010)

Beach profile and tidal adjustment

The dynamics of the daily tides caused over- or under-estimation of the shoreline extracted from satellite images (Figure 34). Tidal coordination to extract the actual shoreline was conducted using the simple mean sea level equation below (Figures 32–35).

$$MSL = \frac{\{(\text{high water level} + \text{low water level})\}}{2} - X \qquad (10)$$

X = Lowest low water below Mean Sea Level

Beach slope was measured between the highest water level and lowest water level for 31 points by the interval every 1 meter using DGPS and calculated in ArcGIS 10.1. The beach profile measured from the lowest water to the coastline about 2.44 m landward and the slope of beach was 3.94 degree (Figure32).

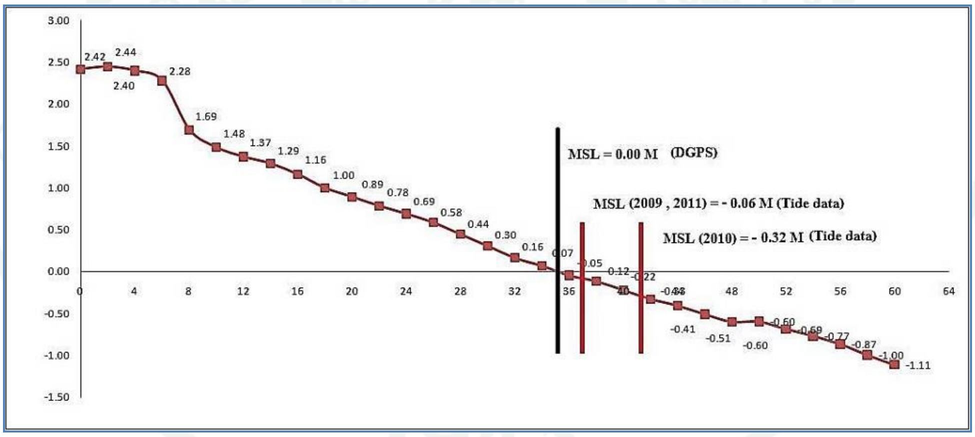


Figure 32 Showing the beach profile at Hat Chao Samran

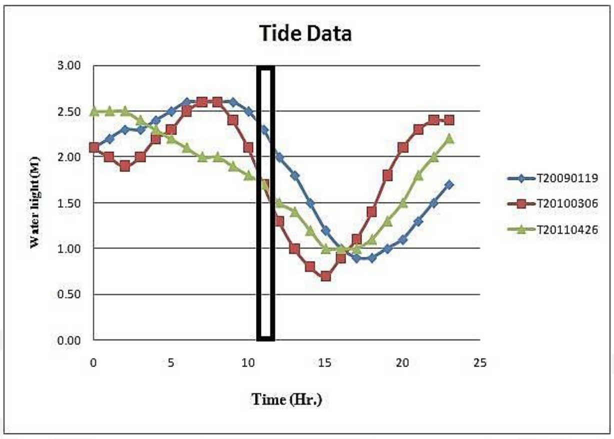
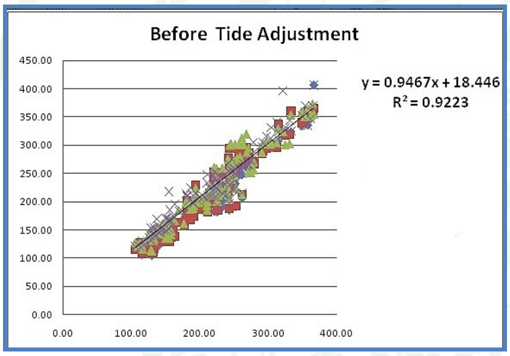
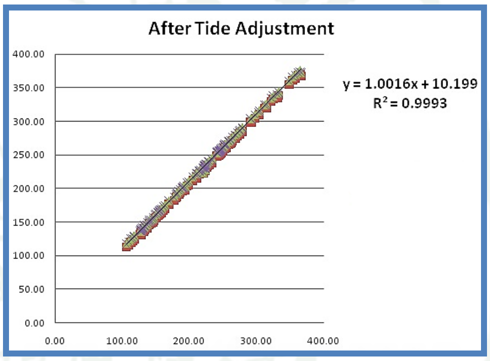


Figure 33 Tidal data from a LANDSAT image on date (10:30 am)



-Fig 34a-



-Fig 34b-

Figure 34 Shoreline before tidal adjustment (a) and after tidal adjustment (b)

Figure 35 The original shoreline extracted from satellite images (red line) and tidally corrected shoreline from satellite images (yellow line)

Source: THAICHOTE (2012)

Sediment characteristics

The sediment particles at Hat Chao Samran are mainly sand with a relatively small diameter of about 0.15 mm. The detailed sediment grain size distribution is shown in Table 11. Because the beach in the study area is not long, the sediment grain size along the beach is fairly homogeneous.

Table 11 The sediment size at Hat Chao Samran

Sediment Types	Gain size (mm.)	Percent (%)
Gravels	>2.00	0
Sand	2.00-0.063	79.3
Silt	0.063-0.0039	0
Clay	<0.0039	20.87

2.2 Present anthropogenic factors

Current land use and breakwater at Hat Chao Samran was surveyed during1–5 April 2013 (Figure 36). The land use mainly consists of mangroves, agriculture and rice fields, aquaculture and salt flats, urban and developed areas, and bare land. The majority of the land use is still rice fields in the middle and lower elevation parts of the study area. Most of the rice fields are planted about 1–2 km from the sea. Many of the former aquaculture areas have been abandoned and developed as resorts.

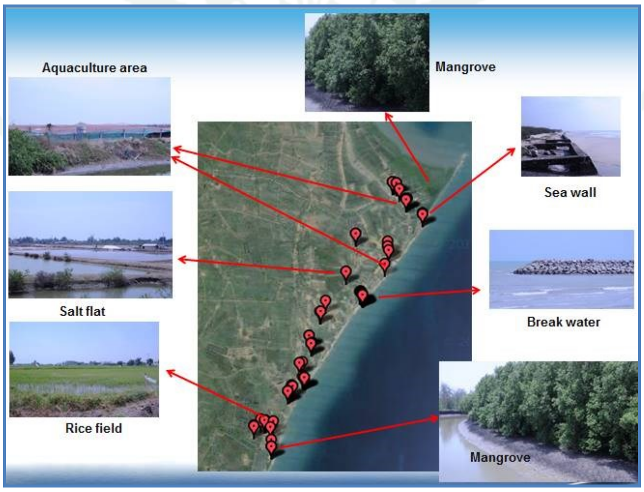


Figure 36 Land use at Hat Chao Samran during1–5 April 2013

In summary, factors affecting to coastal zone change at Hat Chao Samran, Petchaburi Province was divided into two periods: the past (1999-2011) and current (2012-2013).Both the period studied, with emphasis on natural and anthropogenic factors were based on Geo-indicators. Natural factors included strong wind-wave, current, sediment type, beach slope and extreme weather. Anthropogenic factors covered the activities in the areas such as land use and breakwater.

Historical data between1999-2011 found natural factors especially changes in the wind-waves and currents influencing Hat Chao Samran. These factors were dominated by changes in monsoon weather, particularly during the second inter-monsoon (Sep-Oct) and NE monsoon (Nov-Jan). The highest waves were found during the NE monsoon (0.1-3 m), followed by the second inter-monsoon (0.1-2.0 m). The maximum wind speed was observed during the second inter-monsoon (0-. 25 m / s), followed by the NE monsoon (0-21 m / s). The maximum current speed was observed during the second inter-monsoon (56.3-100.0 cm / s), followed by the NE monsoon (77.0-77.9. cm / s). Circulation pattern showed anti-clockwise flow during the NE monsoon and clockwise flow during the SW monsoon. Another natural factor that is very important is extreme weather. Because Hat Chao Samran is a long, straight beach, it is directly influenced by monsoons. Thus, monsoon weather and associated storms are very important influences on coastal zone changes in this area. It recorded the number of storms during October-November each year that came through the Gulf of Thailand, typically 12-18 over the past 60 years.

Also during this time, the changes in human activities influenced the area quite clearly and showed significant increased changes in land use during 1999-2011, particularly in aquaculture (6.12%), agriculture areas (4.94%), and. urban (3.69%), except that mangrove forest areas changed very little (1.21%,). Only bare land decreased by 10.23%. The reason for the change very little in forest area probably due to this study area is adjacent to the royal project (Laem. Pak Bia), where investigations found that during 1957-1991, mangrove invasion and destruction had occurred. Most of this area has been converted to aquaculture. Between 1991 and 1996, the Cabinet agreed to suspend use of the mangrove area and developed rehabilitation policies for regeneration of degraded mangroves. This policy has caused the mangrove area to steadily increase (Satumanatpan, 2012).

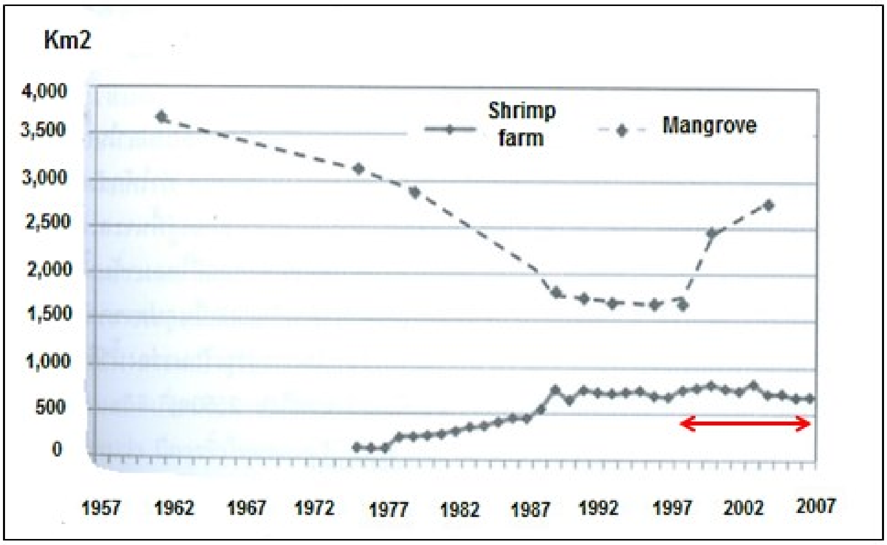


Figure 37 Changes in mangrove areas and shrimp farms during 1961–2007
Source : Satumanatpan (2012)

Considering the present factors during 2013, the present natural factor analysis obtained from coastal radar network in 2013 and found that the maximum wave is in the NE-monsoon (Nov-Jan), followed by the 1st transition period (Feb-Apr).The maximum wind information found in the SW-monsoon (May-Aug), followed by the 1st transition period (Feb-Apr). Maximum current speed found in the 1sttransition period (Feb-Apr) and NE-monsoon (Nov-Jan).It can be seen that during the 1sttransition period (Feb-Apr) was critically affect the Hat Chao Samran. The data from weather summary report in 2013 (Meteorological department, 2013) reported that in 2013, the average annual and monthly temperatures of many areas was higher than normal especially in the summer maximum temperatures was higher than previously measured. In addition weather condition in 2013influenced by high pressure and NE monsoon in winter and southwest monsoon prevails over the rainy season, also influenced by westerly wind moving through upper parts of Thailand in March, April and December as well. Other physical data such as the slope of the beach in the study area is approximately 0.83 m, which is somewhat less steep. The sediment particles at Hat Chao Samran are mainly sand with a relatively small diameter of about 0.15 mm. The sediment grain size along the beach is fairly homogeneous. For the factors of human activities, including land use and protection structures found that breakwater was to reduce the impact of the strength of the winds-wave and also the seawall was to protect the sea level rise. Thus, the strong wind-wave was the factors that influence this area rather than an increase in the sea water level. The present land use mainly consists of mangroves, agriculture and rice fields, aquaculture and salt flats, urban and developed areas, and bare land. The majority of the land use is still rice fields in the middle and lower elevation parts of the study area. Most of the rice fields were planted about 1–2 km from the sea. Many of the former aquaculture areas have been abandoned and developed as resorts. Therefore, a change of man-made activity in this area, especially in the area near the beach is likely to have an impact one side of the beach.

Impacts of Coastal Zone Change

1. Physical changes in the coastal area

Analysis of coastal change using LANDSAT satellite images during 1999–2011 showed that the coast of Hat Chao Samran eroded during 2005–2006 and 2009–2010 by 1.36 km^2 and 1.38 km^2, respectively (Table 12 and Figure 38-39). In addition, we also found accretion in most areas in 2004–2005 and 2008–2009 of a total of 1.49 km^2 and 1.47 km^2, respectively.

Table 12 Erosion and accretion areas during 1999–2011.

Year	Erosion (km^2)	Accretion (km^2)
1999-2000	0.27	0.17
2000-2001	0.02	1.02
2001-2003	0.33	0.02
2003-2004	0.98	0.05
2004-2005	0.04	1.49
2005-2006	1.36	0.06
2006-2007	0.34	0.18
2007-2008	0.24	0.28
2008-2009	0.03	1.47
2009-2010	1.38	0.16
2010-2011	0.29	0.62

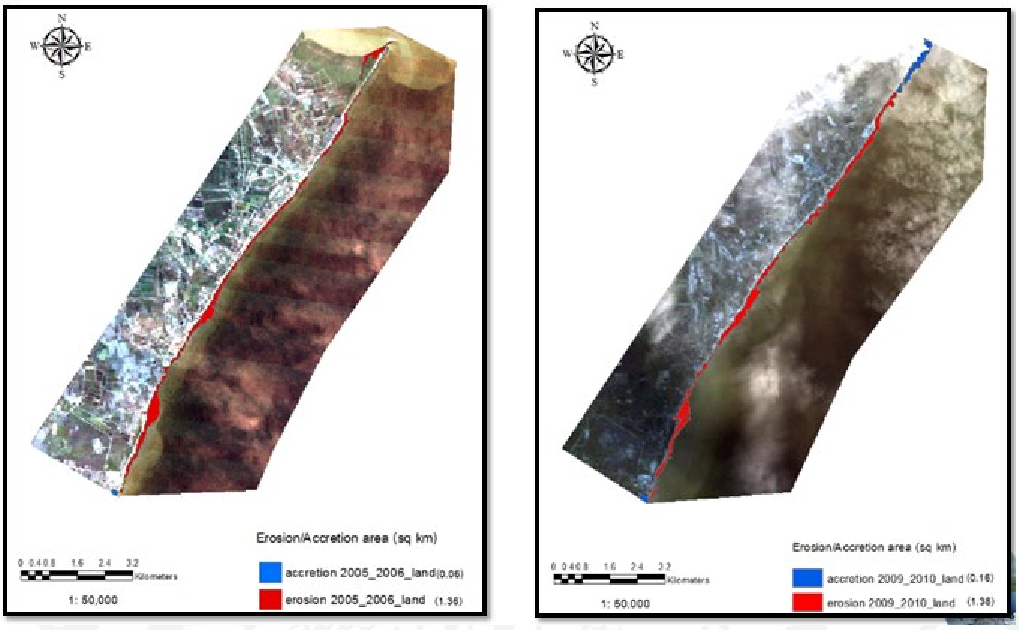


Figure 38 Maximum erosion area during 2005–2006 of about 1.36 km^2 (left) and erosion area during 2009–2010 of about 1.38 km^2 (right) derived from LANDSAT image

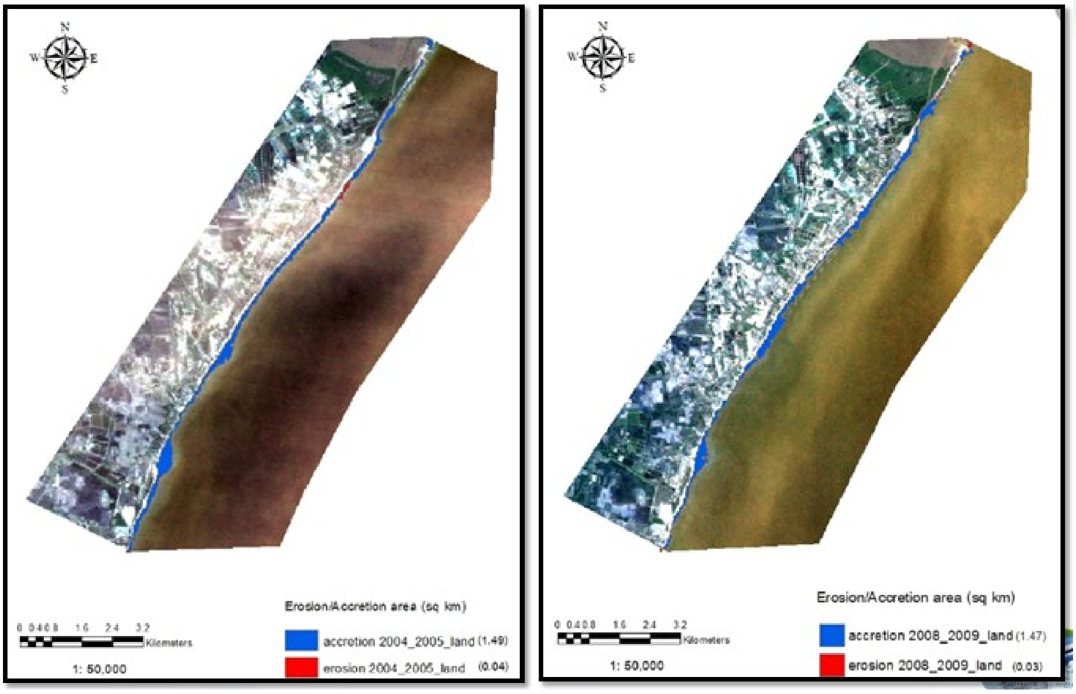


Figure 39 Maximum accretion area during 2004–2005 of about 1.49 km^2 (left) and accretion area during 2008–2009 of about 1.47 km^2 (right) derived from LANDSAT image

We found that changes in the coastal areas causing erosion and accretion effected by both natural factor sand human activities. Erosion and accretion in the study area can be clearly divided into three periods: 1) before the breakwater (1999–2006), 2) construction of the breakwater (2007–2008), and 3) after the construction of the breakwater (2009–2011).

Before breakwater construction (1999–2006):

Analysis of changes in the coastal area was conducted using LANDSAT satellite images before breakwater construction indicated that the area mainly was eroded. The changes in the coastal area during this period are consistent with natural factors such as wind, wave, current and also associated with the monsoon periods, especially in the end of the NE monsoon to the middle of the first inter-monsoon. Analysis of the historical data found that the low currents, flowing from south to north, caused most of the erosion in the southern area and deposition in the northern area (Figure 40).

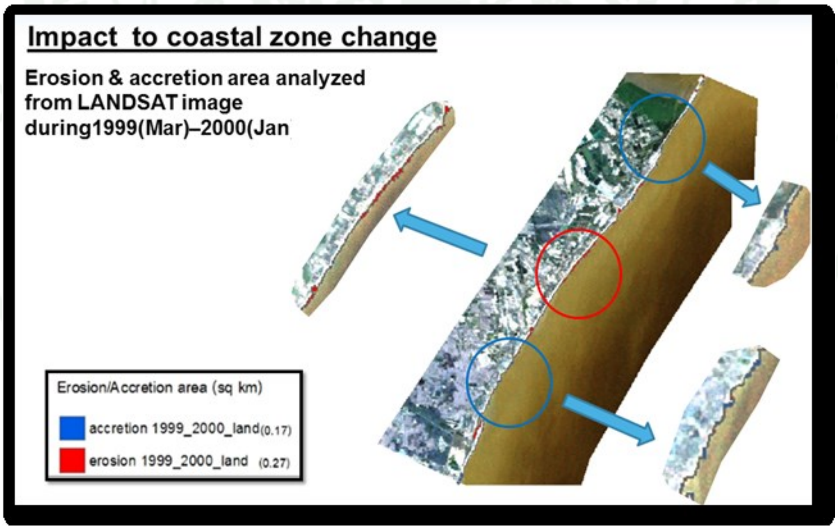


Figure 40 Erosion in southern area and accretion areas in northern area during 1999–2000 derived from LANDSAT image

Generally, the most critical erosion found in July 2005 and December 2006 (Figure 41).The change in this coastal zone were consistent with the strong NE monsoon, which is a major influence on the area ,as well as an increase inhuman activities, such as agriculture, aquaculture, and development of coastal areas. The coast was eroded by13.6 km^2 and there was accretion of only0.06 km^2.

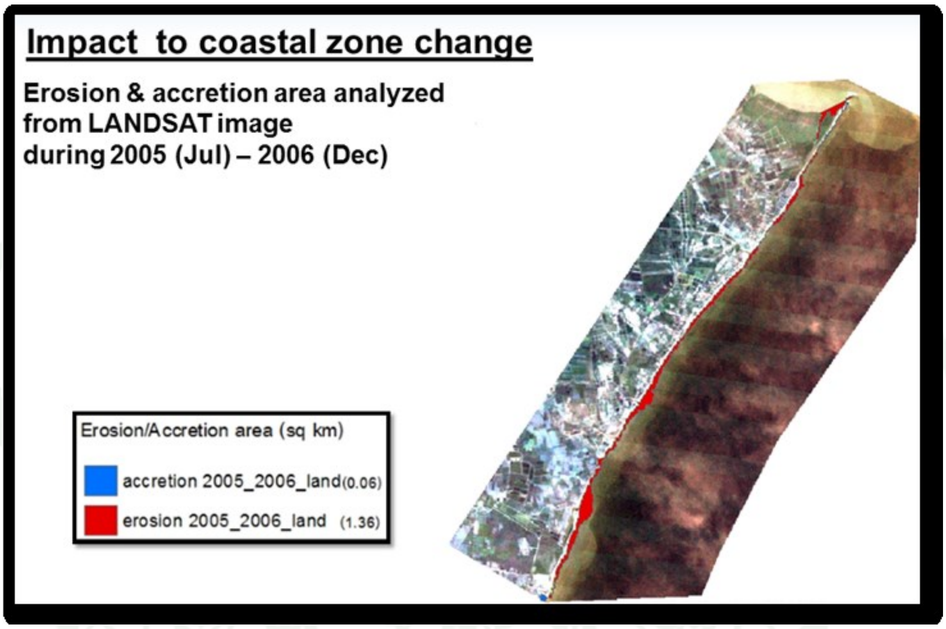


Figure 41 Erosion and accretion areas during 2005–2006 derived from LANDSAT image

During breakwater construction (2007–2008):

Analysis of changes in the coastal area was conducted using LANDSAT satellite images for January 2007 and February 2008, which was during the construction of the breakwater. We found that generally the area was still eroded. This change associated with construction of the breakwater in the area. Analysis of historical data showed that the monsoon season was a factor influencing this area during this time. The current flows from south to north during the first inter-monsoon, causing erosion in the southern area and sediment deposition mainly in the northern area.

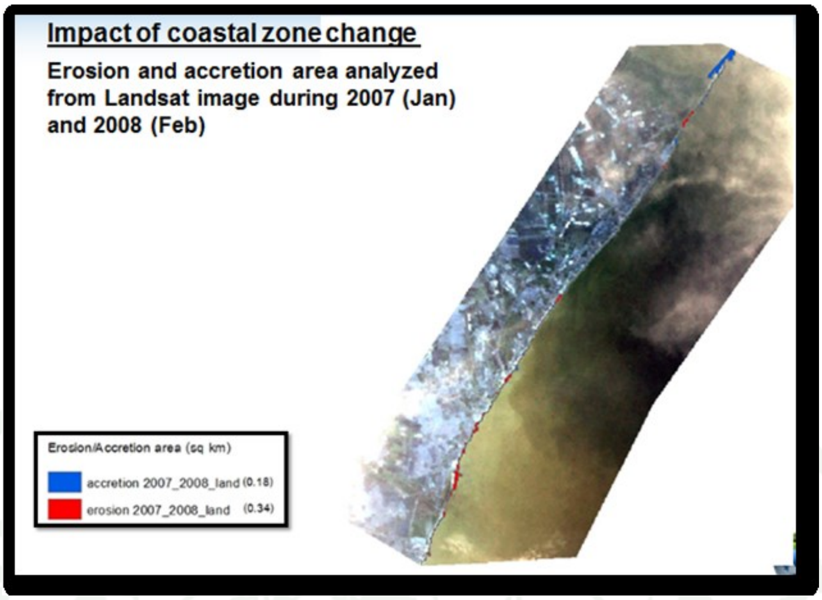


Figure 42 Erosion and accretion areas during 2008–2009 derived from LANDSAT image

After breakwater construction (2009–2011):

Analysis of changes in the coastal area was conducted with LANDSAT satellite images after the breakwater was built. Entirely the accreted area increased (2.25 km^2) and eroded area was reduced (1.7 km^2). Analysis of the waves, wind, and currents during the NE monsoon and the second inter-monsoon showed that the season was a major influence on sediment transport in this area. Avery strong current flowed from north to south, which resulted in erosion in the northern area and accretion to the south. The breakwater also had an influence in the central area, resulted in accumulation of sediment in that area.

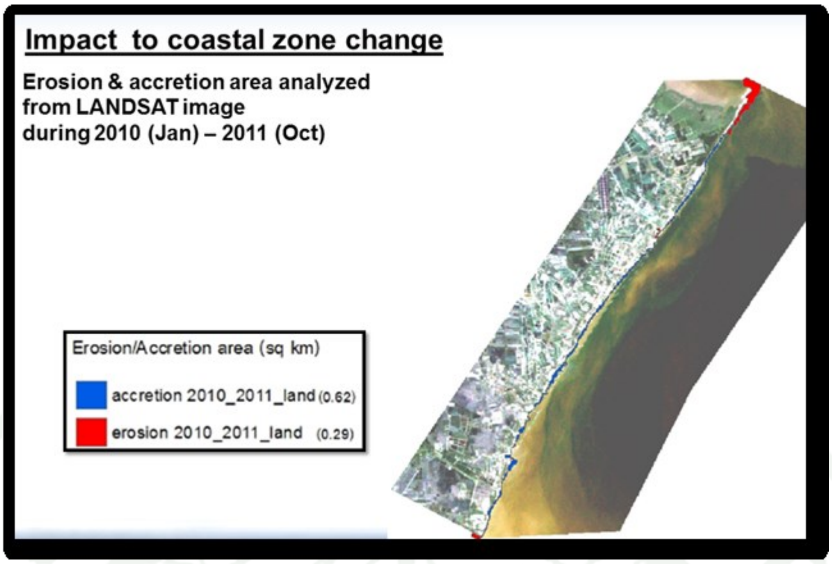


Figure 43 Erosion and accretion areas during 2010–2011 using LANDSAT image

From inspection the study area during 2012-2013 and analyzed THAICHOTE satellite images in 2012found the accreted beach in the central area which has breakwater, but the upper and lower parts of the breakwater clearly has eroded area as Figure 44.

Figure 44 Erosion and accretion areas during 2008–2012 using THAICHOTE image in 2012

2. The spatial relationship between the natural factors and erosion and accretion

In summary, the physical change of the Hat Chao Samran beach, which causes the erosion and accretion were caused by both natural and anthropogenic factors. Considering the natural factors that seasonal changes affect the strength of the wind, wave, current and the movement of sediment along the beach in particularly the2ndtransition (figure 45) and NE monsoon (figure 46).

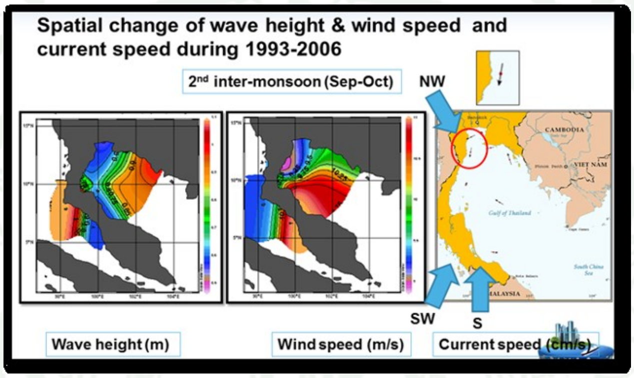


Figure 45 Analysis of spatial changes in waves, wind, and currents during the second inter-monsoon showed that the highest wind-waves found in the eastern part of the Gulf and currents moved sediment from north to south and south to north.

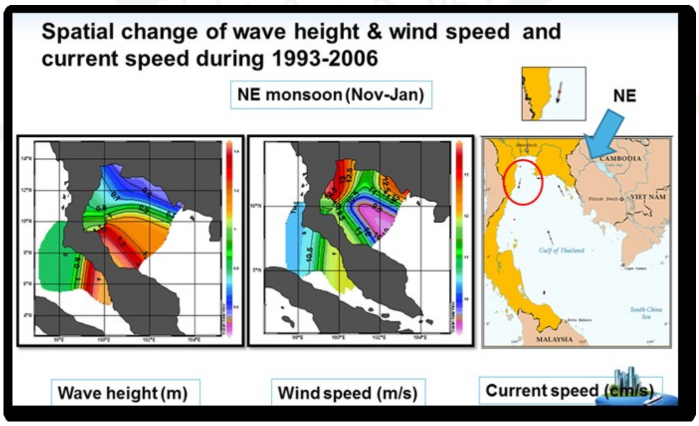


Figure 46 Analysis of spatial changes in waves, wind, and currents during the NE monsoon showed that the highest wind-waves found in the inner Gulf and currents moved sediment from north to south

Due to coastal sediment transport is caused by waves and currents, tides, and wind (Satumanatpan, 2012). With characteristics of stable beach found sediment transport balance in the area, as shown in Figure 47. In contrast, erosion and accretion beach occurred as an imbalance of coastal sediment.

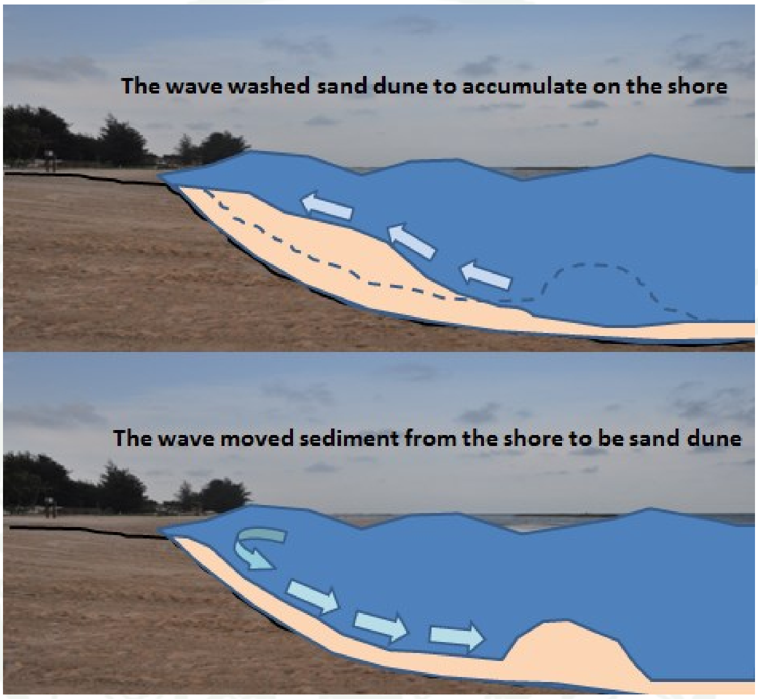


Figure 47 Sediment transport balance between strong wind-waves(monsoon) and calm(non-monsoon) periods

Source: Modified from Satumanatpan (2012)

3. The spatial relationship between the land use and erosion and accretion

Apart from the natural factor we found that physical change in the study area were associated with the land use. The result from physical impact shows the severe erosion that happened in 2005 and 2009. In 2005, the erosion was related to the increases in agricultural area and urban area but decreases in bare land, and aquaculture area. Meanwhile, in 2009, it was related to increases in agricultural and bare land and urban area, while aquaculture was decreasing. The highest accretion levels, in 2004 and 2008, were related to the increases in aquaculture and bare land and urban area but decreases in agricultural area. The relation is shown as Figure 48.

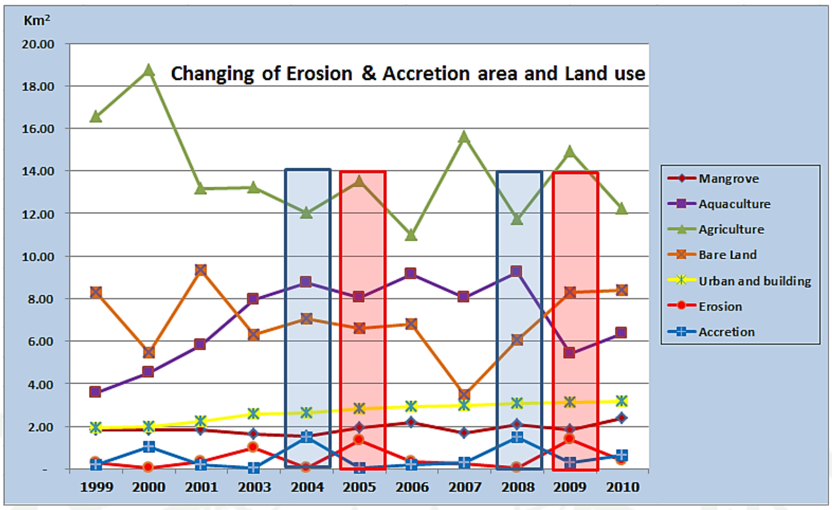


Figure 48 Changes in erosion and accretion areas with land usage from 1999 to 2011

However spatial relationship analysis between erosion and accretion to land use was introduced by using spatial regression technique to gain an understanding of the spatial relationships among land use types that could be factors regarding the coastal zone changes.

4. The relation of erosion and accretion to land use types during 1999 - 2011 using OLS for the whole period

The regression between erosion area and the type of land use from 1999 to 2011 was calculated using the Ordinary Least Square (OLS) technique, and the statistical results are presented in Table 16. The statistical correlation of the erosion equation (Y_1) found the highest probability (P-value) for mangroves, which also had the lowest regression coefficient. This indicates a negative relation between erosion and mangroves. Compared with the others, urban and building area had the highest regression coefficient, followed by aquaculture and salt flats area, bare land, and agriculture and rice fields, respectively. This indicates a positive relationship with coastal erosion, which means that as urban and building and aquaculture and salt flats areas in creased, coastal erosion increased significantly. This can be summarized by saying that the coastal area change within this period has a negative association with mangroves, that is, more mangroves led to less erosion, and also positively related to urban and building area, that is, more expansion of urban and building area led to more erosion.

The regression between accretion area and the type of land use from 1999 to 2011 was calculated using the OLS technique, and the statistical results are presented in Table 16. The probabilities (P-values) reflected high significance for all land use types. Among land use types, aquaculture area had a higher probability than the others. The regression coefficient calculated for the urban and building area had a negative relationship with accretion, while the other land use types had positive relationships. Among the positive relationships, aquaculture and salt flats area had the strongest positive relationship. The accretion within this period was thus associated with all land use types with high probability in both positive and negative relationships.

Table 13 Statistical correlation from OLS for erosion (Y_1) and accretion (Y_2) with land use types during 12 years (1999-2011).

	Erosion		**Accretion**	
	Coefficients	**P-value**	**Coefficients**	**P-value**
Intercept	-19.8929	0.2269	-1.5946	0.9426
Mangroves (X_1)	-0.0025*	0.9980*	0.1379	0.9267
Aquaculture area & salt flat (X_2)	0.6643	0.2918	0.1657	0.8482
Agriculture and rice field (X_3)	0.6261	0.2288	0.0677	0.9229
Bare land (X_4)	0.6622	0.1905	0.0368	0.9563
Urban and building area (X_5)	0.9221	0.1497	-0.1822*	0.8268*
Regression statistic (R^2)	0.4946		0.0769	

(*)The relationship between mangrove and erosion, urban area and accretion showed the low coefficient and high p-value. This variable with coefficient nears zero and high P-value do not help predict or model the dependent variable; it was almost removed from the regression equation, but it has strong theoretical reasons to keep it. Since it is well known that mangrove is vital to the protection of coastal areas, but in this study area has less mangrove area compared to other areas, thus providing a low

coefficient and high P-values. The same as urban area has increasing since 1999, it has less area compared to other areas, thus providing a low coefficient.
(R^2) The value of R-squared ranges from 0 to 100 percent. If model fits the observed dependent variable values perfectly, R-squared is 1.0. The erosion model explains 49 percent of the variations (land use types) in the dependent variable (erosion area) and the accretion model explains 7 percent of the variations (land use types) in the dependent variable (accretion area).

5. The relation of erosion and accretion to land use types during 1999-2011 using GWR for each year

From Table 14, the correlation between the type of land use on erosion and accretion presented a correlation between every year except 2007, 2010 and 2011. These years had very low $R^2$and regression coefficient between X_i and Y_i erosion and accretion. This indicated that coastal zone change in these years was not associated with changes in land use but instead could come from other causes, such as extreme weather, especially in 2007and the breakwaters in the area and so on. However the comparison during the critical erosion and accretion expressed the relationship of the equation, as detailed below.

The actual relationships between land use type and erosion, the regression coefficients from 1999–2011, were computed using Geographical Weighted Regression (GWR), as shown in Table 17. The results show thatduring2005, which was one of the most erosion-prone years, the regression coefficient for bare land was highest, followed by that for urban and building area. This indicates that erosion during 2005 was associated with bare land and urban and building area. The second highest period of erosion, in 2009, showed a maximum regression coefficient for urban and building area. This represents a positive relationship with coastal erosion. That is, as urban and building area increased, coastal erosion increased significantly. The results in Table 3 indicate that mangroves had no significant impact on erosion during these periods.

The relationships between land use type and accretion were computed using GWR and are shown in Table 14. The results show thatduring2004, which was one of the most coastal accretion-prone years, the regression coefficient for bare land was highest. This indicates a positive relationship with coastal accretion, which means that as bare land increased, coastal accretion increased significantly. The second highest period of accretion was in 2008, when the regression coefficients for mangroves and urban and building area were highest. This indicates a positive relationship with coastal accretion. That is, as mangroves and urban and building area increased, coastal accretion increased significantly. The results in Table 17 also show that the regression equation for urban and building area and accretion was statistically significant.

Table 14 Statistical correlations from GWR for erosion (Y_1) and accretion (Y_2) with land use types from 1999–2011

	Regression coefficient Mangroves (X_1)		Regression coefficient Aquaculture and salt flats (X_2)		Regression coefficient Agriculture and rice fields (X_3)		Regression coefficient Bare land (X_4)		Regression coefficient Urban and building (X5)		Erosion		Accretion	
	Erosion	**Accretion**	**Erosion**	**Accretion**	**Erosion**	**Accretion**	**Erosion**	**Accretion**	**Erosion**	**Accretion**	**R^2**	**P value**	**R^2**	**P value**
1999	0.1553	0.1006	0.0005	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0007	– 0.0001	0.98	0.011	0.99	0.011
2000	0.0148	0.6301	– 0.0004	– 0.0018	0.0000	0.0000	-0.00003	– 0.0014	– 0.0040	– 0.1746	0.94	0.011	0.91	0.021
2001	0.0947	0.0947	– 0.0005	–0.00005	0.0000	0.0000	0.0000	0.0000	– 0.0002	–0.00029	0.99	0.023	0.98	0.033
2004	-0.0003	-0.0128	–0.0001	–0.0048	-0.0014	-0.0563	0.0876	3.5922	–0.0198	–0.8130	0.65	0.342	0.61	0.382
2005	0.0075	0.0033	–0.0021	–0.00009	0.0030	0.0001	2.4164	0.1061	0.1377	0.0060	0.95	0.786	0.91	0.681
2006	0.0190	0.0102	0.0000	0.0000	0.0042	0.0023	0.0012	-0.0006	0.0000	0.0000	0.99	0.202	0.92	0.002
2007	-0.0003	-0.0002	-0.0013	-0.0069	-0.0002	-0.0001	0.0015	0.0081	-0.0031	-0.0017	0.04*	0.183	0.15*	0.00003
2008	0.0177	0.7957	-0.0004	-0.0172	0.0000	-0.0006	0.0000	0.0000	0.0000	0.0018	0.89	0.021	0.99	0.00003
2009	0.3636	0.0360	-0.0064	-0.0044	-0.1268	-0.0311	-0.0663	-0.0845	0.0756	0.4269	0.99	0.264	0.97	0.871
2010	0.2679	0.0088	-0.0007	0.0018	-0.0057	-0.0122	-0.0015	-0.0005	0.0082	0.0097	0.21*	0.122	0.13*	0.122
2011	0.0010	0.0047	0.0023	0.0049	-0.0020	0.0019	-0.0001	-0.0003	0.0005	-0.0118	0.02*	0.065	0.04*	0.739

(*R^2) Erosion and accretion model for each year indicate a relationship with different land use types. The low $R^2$of erosion model and accretion model in 2007, 2010 and 2011 explain low relationship of the variations (land use types) in the dependent variables (erosion and accretion area).It means that these three years, the erosion and accretion had low relation to land use types, it might be related to other factors such as natural factors.

6. Spatial statistical relationships

The relationships between erosion and accretion with land use can be displayed using the parts of the regression coefficients and standard residuals that vary over space, as shown in Figure 49-50. This indicates that the types of land use that influenced erosion in descending order were urban, aquaculture, bare land, mangroves, and agriculture. Also, the types of land use that influenced accretion in descending order were urban, aquaculture, mangroves, bare land, and agriculture.

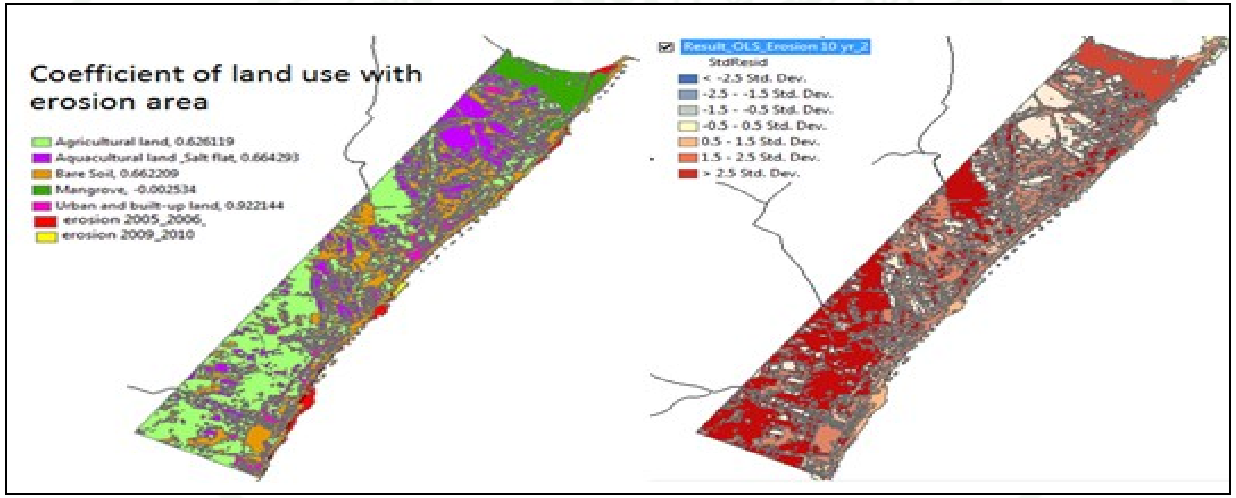


Figure 49 Regression coefficients for land use and erosion during 1999–2011. The maximum regression coefficients were for urban, aquaculture, bare land, agriculture, and mangroves (left) and Residuals for land use and erosion during 1999–2011. The minimum standard deviations were for aquaculture, urban, bare land, mangroves, and agriculture (right)

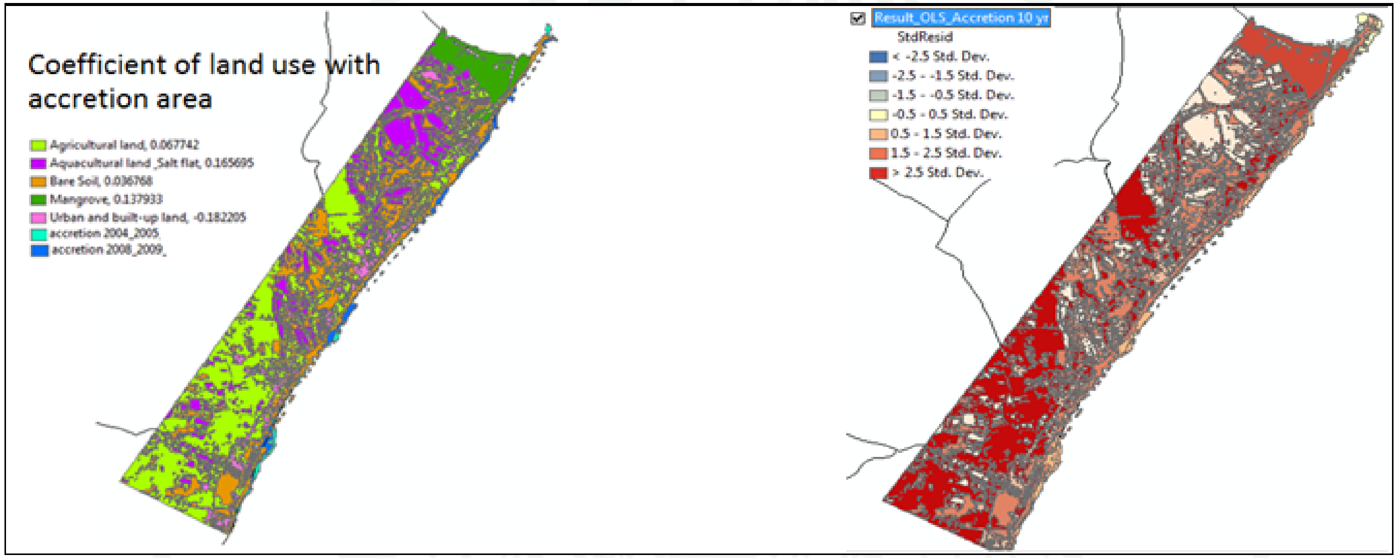


Figure 50 Regression coefficients for land use and accretion during 1999–2011. The maximum regression coefficients were for urban, aquaculture, mangroves, agriculture, and bare land (left) and Standard Residuals for land use and accretion during 1999–2011. The minimum standard deviations were for aquaculture, urban, bare land, mangroves, and agriculture (right)

7. Spatial autocorrelation

Spatial autocorrelation is based on feature locations and attribute values using the Global Moran's I statistic. The Global Moran's I tool calculates a Z-score and P-value to indicate the validity of the null hypothesis and states whether feature values are randomly distributed across the study area. The spatial autocorrelation between erosion and land use was done using erosion and land use residuals and resulted in a Z score of -1.22 and a P-value of 0.22.This pattern indicates that the regression residuals are spatially random. In the case of accretion and land use, the analysis resulted in a Z score of -0.35 and a P-value of 0.73, which is quite high. This feature pattern indicates that the regression residuals still are spatially random. It also indicates that the OLS results of both events can be trusted.

8. Performance of the regression model

Erosion regression model: the multiple linear regressions for the dynamics of erosion from Table 2 can be expressed as Eq. 11. The model's performance can be described in terms of the R-squared (R^2) value, which was about 0.49. This is a quite preferable result. The regression coefficient of mangroves represented the lowest value.

Erosion regression equation (Y_1)

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon \quad (11)$$

$$\text{Erosion} = -19.8929 - 0.0025X_1 + 0.6643X_2 + 0.6261X_3 + 0.6622X_4 + 0.9221X_5, \quad R^2 = 0.49$$

Accretion regression model: the multiple linear regressions for the dynamics of accretion from Table 2 can be expressed as Eq. 12. The model's performance in terms of the R-squared (R^2) value was about 0.07, which was not preferable. The results included a high probability (P-value) for urban and building area, which had the lowest regression coefficient.

Accretion regression equation (Y_2)

$$Y_2 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon \quad (12)$$

$$\text{Accretion} = -1.5946 + 0.1379X_1 + 0.1657X_2 + 0.0677X_3 + 0.0368X_4 - 0.1822X_5, \quad R^2 = 0.07$$

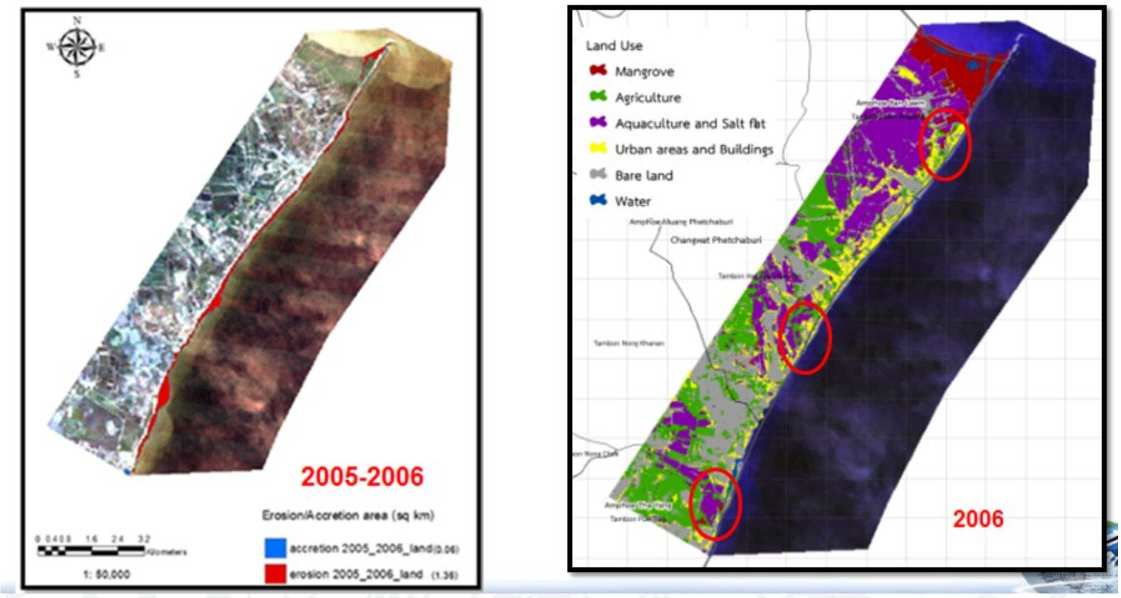


Figure 51 Coastal zone change (left) and land use (right) in study area before construction of the breakwater

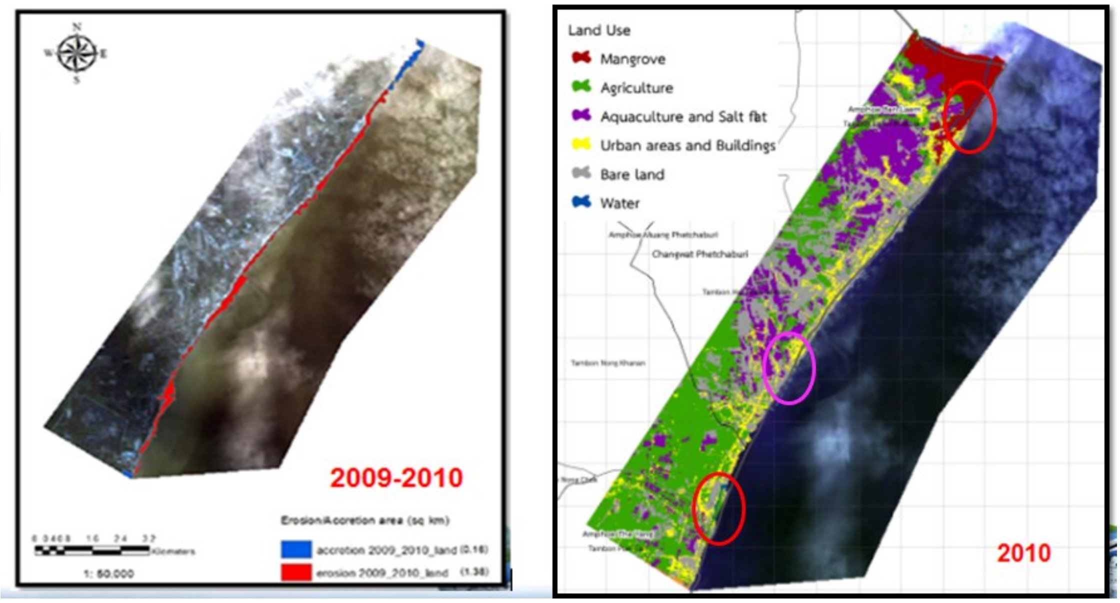


Figure 52 Coastal zone change (left) and land use change (right) after construction of the breakwater

9. Influence of breakwater against erosion and accretion.

Because of erosion problem in the area, especially in 2005-2006, the Hat Chao Samran municipal district allocated a budget to build breakwaters to prevent erosion and to maintain the whole beach. Breakwaters were completed in 2008.Inevitably, the structure of breakwater beach effected to the beach changing, namely coastal sediment transport accreted in front of the breakwater and eroded behind the breakwater as Figure 53.

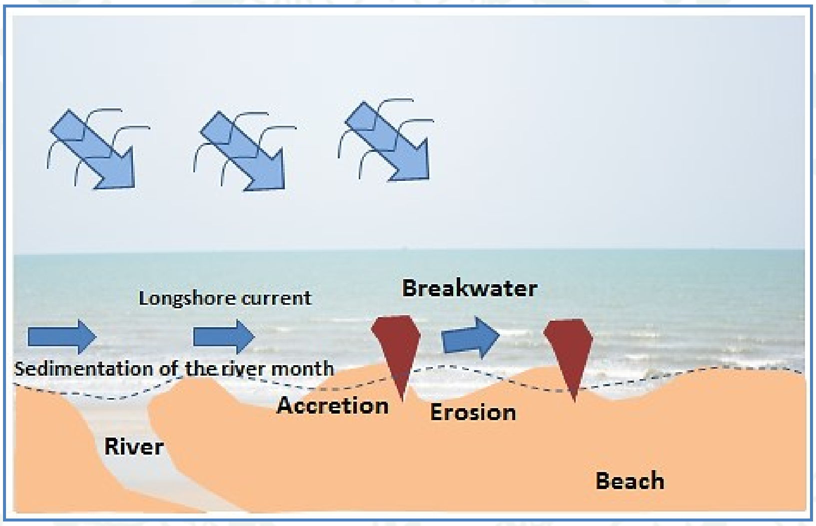


Figure 53 Coastal sediment transport scenario showing accretion in front of the breakwater and erosion behind the breakwater; the dotted line is the coast line

Source: Modified from Satumanatpan (2012)

In summary, we found that physical changes in the coastal areas causing erosion and accretion effected by both natural factors and human activities. Erosion and accretion in the study area can be clearly divided into three periods as following;

Before the breakwater (1999–2006):

Erosion was critical problem which caused by wind, wave, current dominated by 2nd transition and NE monsoon. The land use that influenced erosion in descending order was urban, aquaculture, bare land, mangroves, and agriculture.

Construction of the breakwater (2007–2008):

Accretion was dominant. By analyzing the spatial relationship of land use types found that affected erosion and accretion area in every year except in 2007, 2010 and 2011, which natural factors that influenced this area, especially in 2007 had a number of tropical storms passed through the area more than usual as Fig 27a.Breakwater was only anthropogenic factor indicated more influence than natural factor.

After the construction of the breakwater (2009–2011):

Erosion and accretion were still problem. The natural factors in normal and extreme weather influenced the area, especially in 2010 and 2011. Breakwater and land use, especially increasing in aquaculture and urban were related factor.

Shoreline change predictive model

The previous analysis of physical change in terms of erosion and accretion shows a change in many parts of study area and there is also a breakwater to protect the area. Thus, there are serious doubts for the future change in the area. In this case the shoreline change predictive model is introduced. Shoreline change predictive modelling was conducted using shoreline vectors extracted from LANDSAT images for 1999–2011. The erosion rate was also computed using the baseline measurement method to calculate rate-of-change statistics from the time series of shorelines using DSAS (Himmelstoss, 2009). Prediction of shoreline changes was conducted for three different time periods, the short term (5 yr), medium term (10 yr), and long term (20 yr). The results are shown in Figure 54-56.

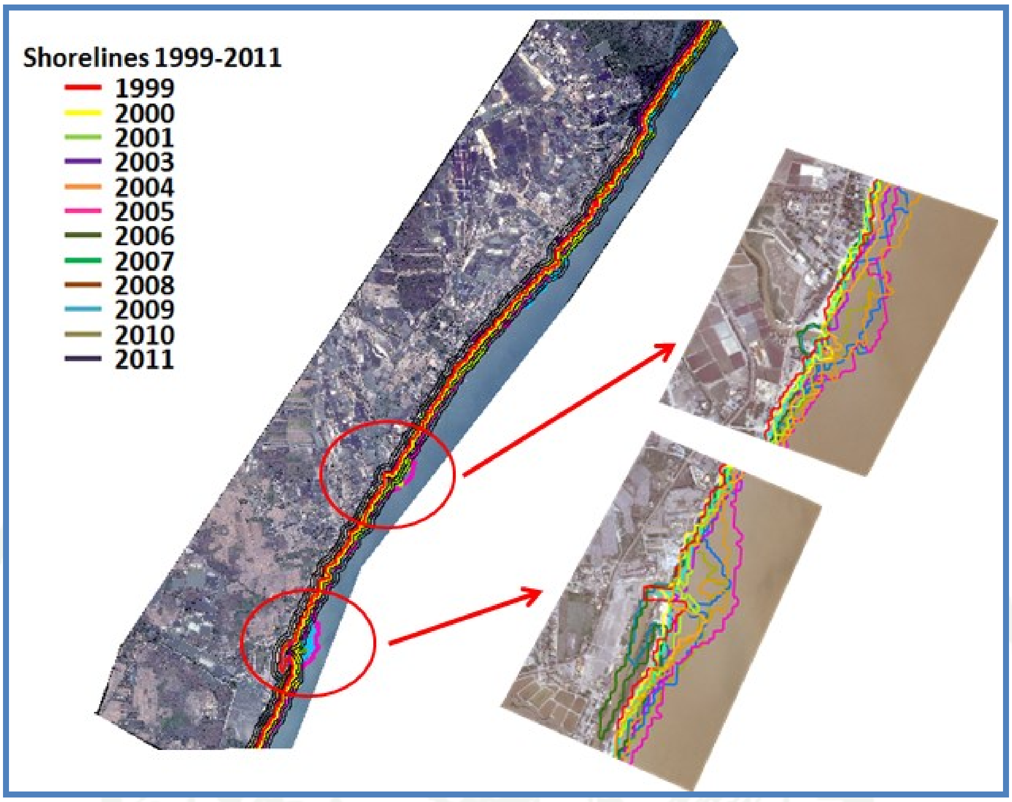


Figure 54 Changes in the shoreline extracted from LANDSAT images for 1999–2011

Calculation of the rate of change from 1999 to 2011 showed that the southern area had the most severe erosion rate of more than 5 m/yr, followed by the central area with an erosion rate of 0–4.9 m/yr and an accretion rate of 1–10 m/yr. The northern area had a high accretion rate of over 10 m/yr. According to Sinsakul *et al.* (2002) and DMCR (2012), coastal changes can be classified as follows:

- Severely erosional coasts with an erosion rate of>5m/yr
- Moderately erosional coasts with an erosion rate of1–5m/yr
- Depositional coasts with a deposition rate of 1–5m/yr
- Stable coasts with a change rate of ±1 m/yr

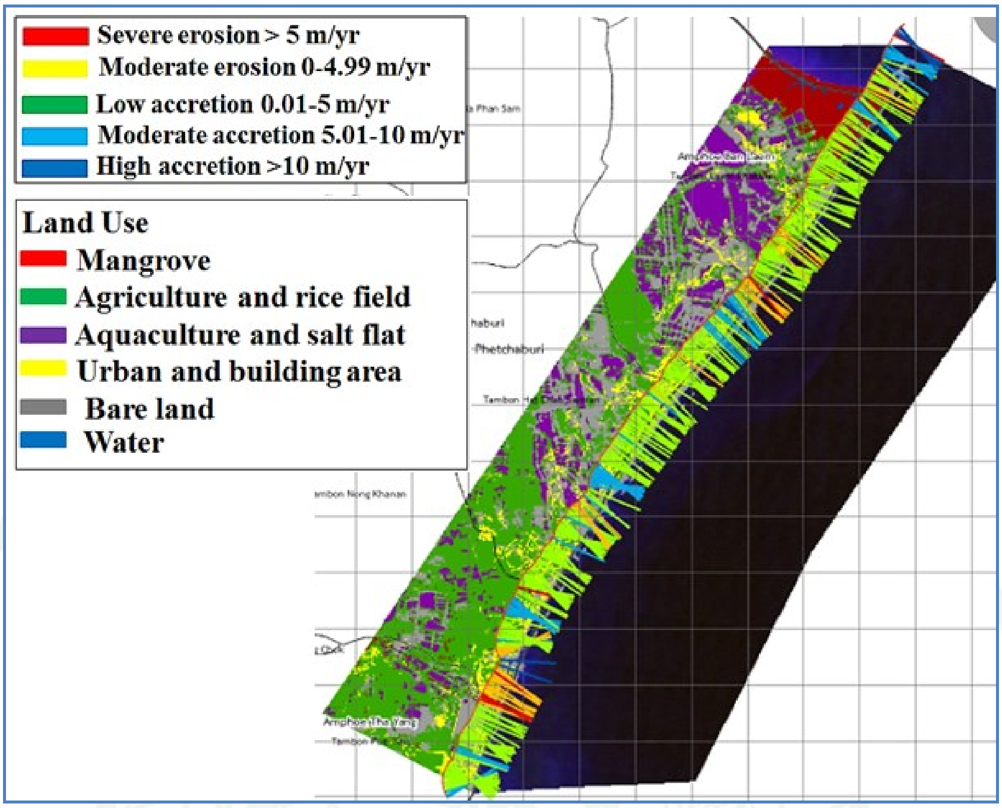


Figure 55 Coastal change rates in Hat Chao Samran calculated using DSAS

Future shoreline changes were predicted over the short term (5 yr), medium term (10 yr), and long term (20 yr). Rates of coastal erosion in the study area are likely to increase. By 2016, the distance between the baseline and the new coastline is predicted to be 521.824 m, a loss of about 6.07 m compared to 2011.In another 10 years, the distance between the baseline and the 2021 coastline is predicted to be 527.894 m, a loss of about 12.14 m compared to 2011.Finally, in another 20 years, the distance between the baseline and the coastline in 2031 is predicted to be 540.034 m, a loss of about 24.28 m compared to 2011 (Figures 53 and 54).The severity of erosion can be divided into critical, moderate, and low as shown in Table 15.The predictive equation for shoreline change (Eq.13) is as follows:

$$Y = 1.214x - 1925.6,\ R^2 = 0.0216 \quad (13)$$

From equation 13 shows that the $R^2$is very low, this is possible due to several reasons, such as the small number of shoreline vectors and too long period of shoreline change prediction. Moreover, the cause of the coastal area change or shoreline change caused by many factors, so prediction change by using only the time series of shoreline may inadequate.

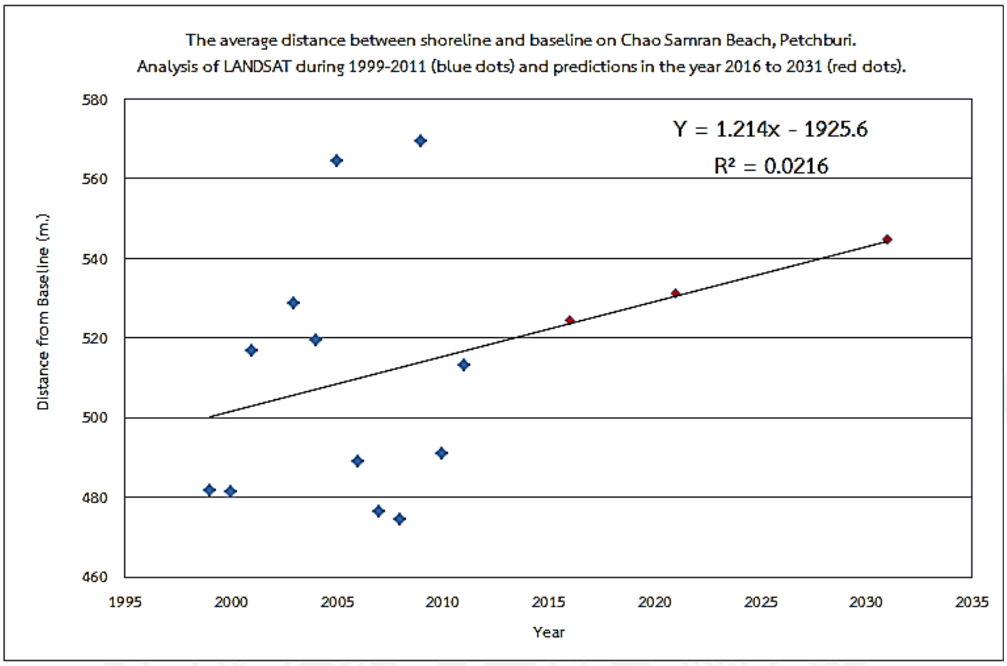


Figure 56 The average distance between shoreline and baseline at Hat Chao Samran, Petchaburi Province; shoreline in 1999–2011 (blue dots) and predictions for 2016–2031 (red dots)

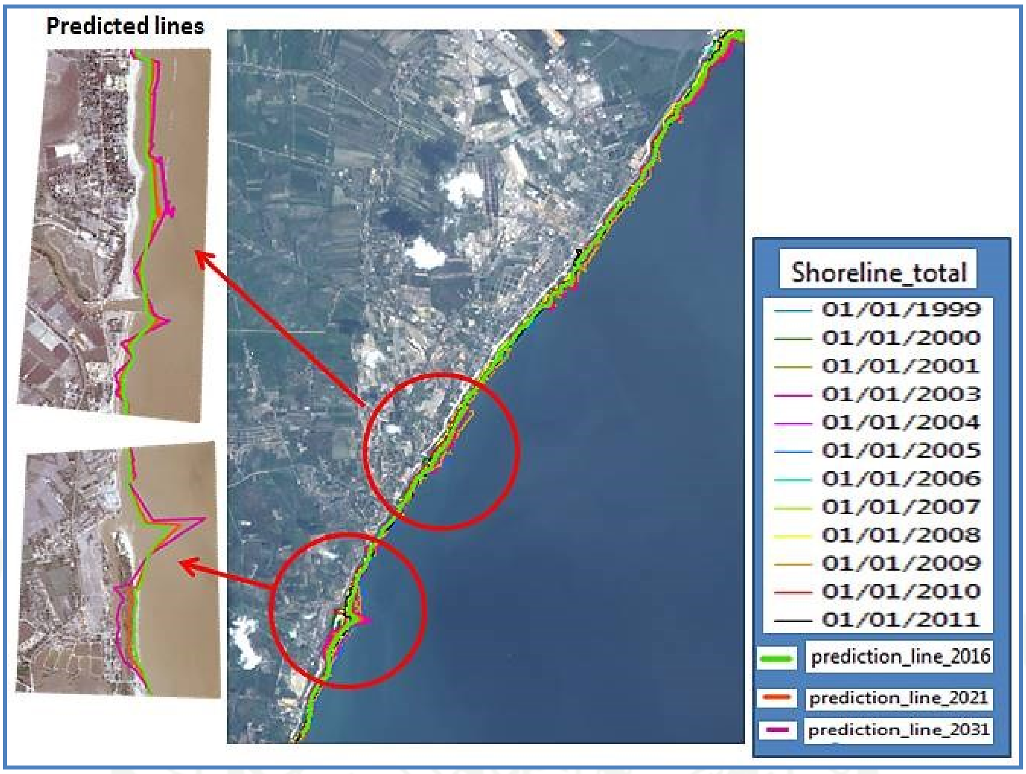


Figure 57 Change in the shoreline during 1999–2011 and predictions for 2016, 2021, and 2031

In summary, the analysis of shoreline change using the shoreline change predictive model (DSAS), we found the rate of change from 1999 to 2011 showed that the southern area had the most severe erosion rate of more than 5 m / yr, followed by the central area with an erosion rate of 0. -4.9 m /yr and an accretion rate of 1-10 m / yr (Figure 59). The northern area had a high accretion rate of over 10 m / yr. For the future change, the short term (5 yr) by 2016, the distance between the baseline and the new coastline is predicted to be 521.824 m, a loss of about 6.07 m compared to 2011.In another 10 years, the distance between the baseline and the 2021 coastline is predicted to be 527.894 m, a loss of about 12.14 m compared to 2011.Finally, in another 20 years, the distance between the baseline and the coastline in 2031 is predicted to be 540.034 m, a loss of about 24.28 m compared to 2011.The predictive equation for shoreline change is $Y = 1.214x–1925.6$, $R^2 = 0.0216$. If there is more time series of shoreline vectors, the R^2could be higher.

According to the analysis under section 3 shows that the shoreline is changing as predictive model or not, it depends on many factors such as characteristics of natural factors, land use in the area and management policies of Hat Chao Samran municipality. However, the predicted shorelines in the next 5 years, 10 years and 20 years, the analysis provided interesting information that the central part of beach was deposited, but the lower part found increased erosion.

10. Social impact

Apart from physical change problem, erosion and accretion also affected the lifestyle of people in the area, such as the loss of residence and livelihood, making traditional lifestyle change and cause conflicts between people in adjacent areas, including the agencies involved. Assessment of the social impacts in this study focused on the potential need for settlement and safety zone for the residential.

Historical coastlines from 1999–2011 and population increases in urban areas near the shoreline were analyzed using overlays in ArcGIS. The results are shown in Figures 20-31 in Appendix B. Analysis of the dynamics of urban settlements in Hat Chao Samran found that the population has increased gradually since 1999, with settlement of agricultural areas away from the coast and in the central area near the beach (Figure 69). Since 2004, the population of shoreline communities has increased markedly and the communities have expanded southward adjacent to Cha-am beach and increased in size. Expansion of these communities was related to beach erosion. Most of the erosion occurred in the southern area, with expansion of the communities and infrastructure. Most of the deposition was in the northern area, which experienced little population growth. The impacts of coastal erosion on the social amenities of the study area were evaluated based on information from knowledgeable individuals, interviewing key informants and annual reports using statistical analysis and overlays technique in ArcGIS.

The results of statistical analysis from Hat Chao Samran annual reports are the following.

Income: Synthesis of data from the Phetchaburi Province Statistical Office and reports of the Hat Chao Samran Municipal District in 2012 determined that the average income of Hat Chao Samran Municipal District was 36.6 million baht and the income per capita was approximately 20,824 baht (Figure 58). The number of tourists per year was about 33,600 and revenue from tourism was approximately 13,440,000 baht/yr with each visitor spending about 400 baht per person. Agriculture was the main source of income in the Hat Chao Samran Municipal District. Income from rice and others commodities was 59.29%, followed by income from tourism at 36.6% (Figure 58).

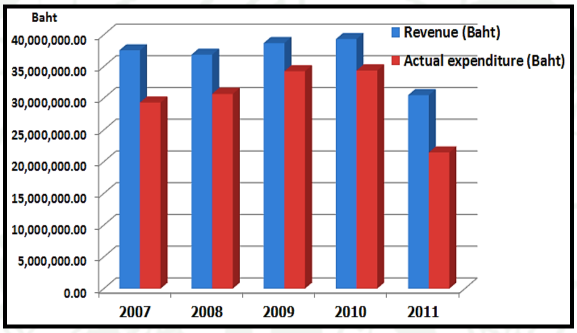


Figure 58 Yearly revenue and expenditures of the Hat Chao Samran Municipal District

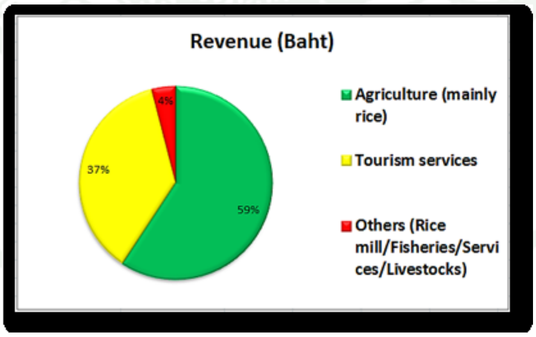


Figure 59 Sources of revenue in the Hat Chao Samran Municipal District during 2007–2011.

Population: The Agricultural Office of Phetchaburi Province reported that Chao Samran Beach had 7 villages with a total population of 299 households, increasing continuously from 2008 to 2012, with a population density of 240 people/km^2 (Figure 60).

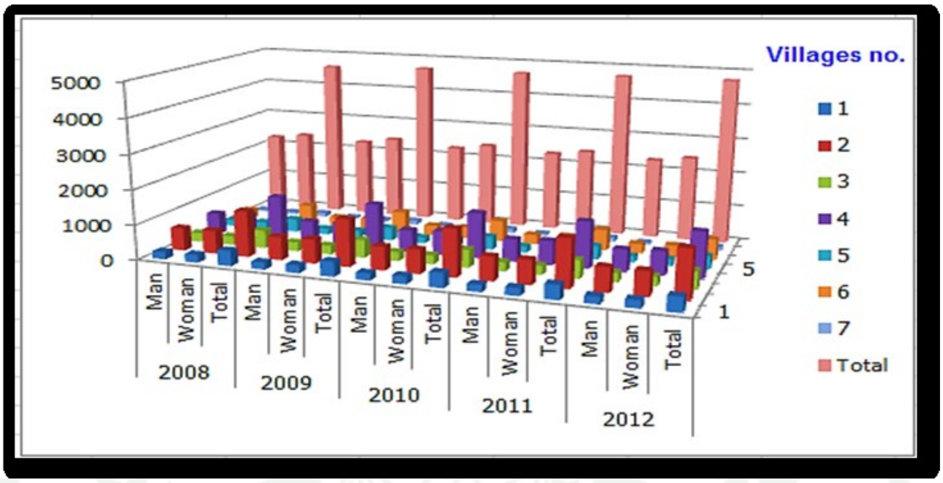


Figure 60 Demographics data showing an increase in population from 2008 to 2012

The statistical analysis from interviewing of key informants is as below;

Interviews were conducted in Hat Chao Samran to further evaluate expansion and satisfaction of residents in the communities near Chao Samran beach. A sample of 100 individuals among the total population of 4,700 people was selected, with a 90% confidence interval (Yamane, 1967). The 100 interviewees differed in gender, age, residential area, occupation, education, religion, and income. The sample group consisted of 60% local and 40% non-local residents. The main occupations were entrepreneur, farmer, government official, and other. While 80% of the individuals owned their property, the remaining 20% rented.

Table 18 Groups of interviewees.

Interviewees	Homestead		Gender		Age (year)		Education		Member of family		Religion	
	Population inside Petchaburi	Population outside Petchaburi	Female	Male	<40	>40	<Bsc.	>Bsc.	<3	>3	Buddhism	Others
Local Tourists	10	20	15	13	20	9	26	6	5	17	20	5
Entrepreneur (Grocery/Resort /Construction)	10	10	14	10	6	10	16	5	8	10	18	3
Agriculture (Rice/Shrimp farm/ Horticulture/palm/ Vegetables/Fishery)	10			17		14	9	4	10	9	15	3
Official	10			9	3	12	10	7	9	6	15	5
Others (Employees etc.)	19	11	13	9	16	10	16	1	9	17	12	4
Total	59	41	42	58	45	55	77	23	41	59	80	20

Resident group:

Interviewed group consists of people in the area by 59% and people outside the area at 41%.

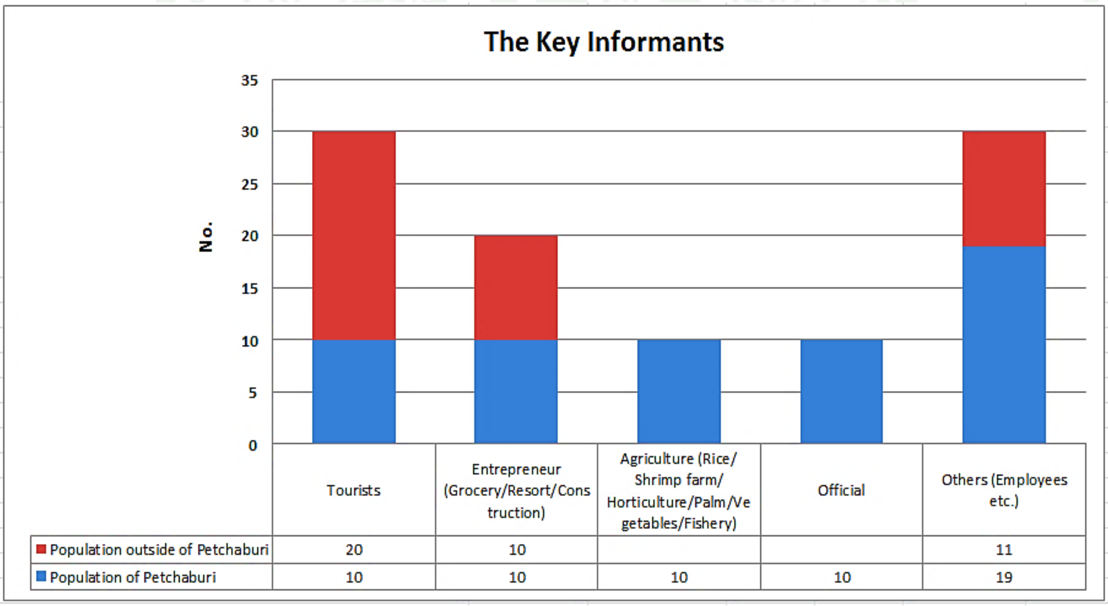


Figure 61 The interviewees consisted of 59% Petchaburi residents and 41% from outside Petchaburi

Revenue:

The income of person who was interviewed about 40% earn between 20,000-40,000 baht per month.

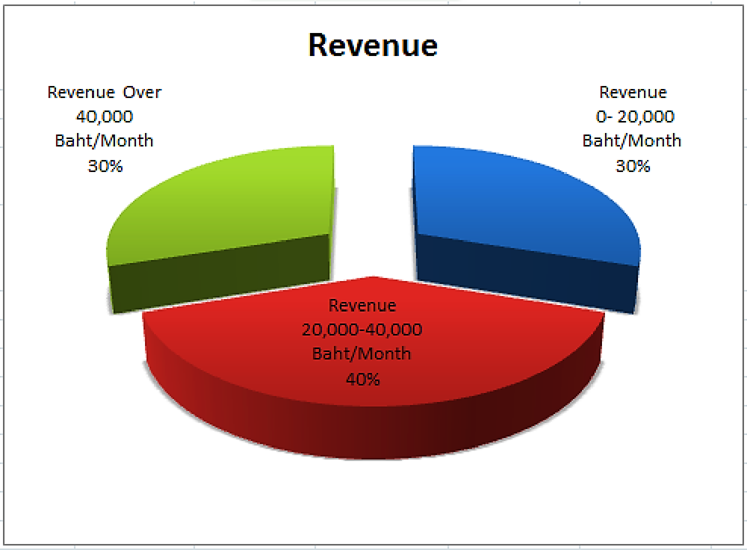


Figure 62 Most of the interviewees had an income of 20,000-40,000 baht/month

Satisfaction-dissatisfaction with Hat Chao Samran:

Most satisfaction with Hat Chao Samran is the convenience of traveling and most dissatisfaction is the turbidity of the water at Chao Samran beach.

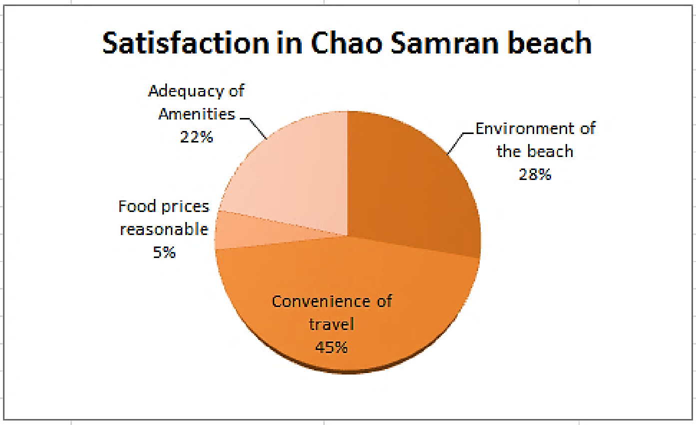


Figure 63 Interviewees expressed the highest level of satisfaction regarding the convenience of traveling to Chao Samran beach

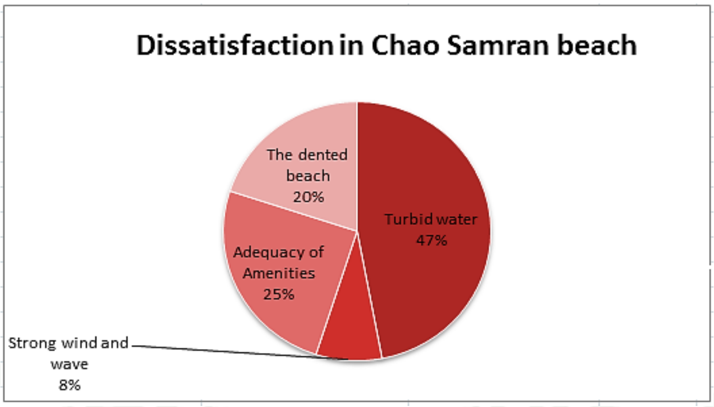


Figure 64 Interviewees expressed the highest level of dissatisfaction with the turbidity of the water at Chao Samran beach

Land Tenure:

The groups that were interviewed, most are owned the land. Details of the group are shown in Table 15.

Table 15 Land tenure.

Interviewees	Land tenure	
	Owner	**Renter**
Local Tourists	15	5
Entrepreneur (Grocery/Resort/Construction)	15	10
Agriculture (Rice/Shrimp farm/Horticulture/ Palm/Vegetables/Fishery)	20	0
Official	15	0
Others (Employees etc.)	15	5
Total	80	20

Number of visits and activities on the beach:

Most people came to Hat Chao Samran more than 2 times. The most favorite activity is sitting and relaxing on this beach.

Table 16 Activities on the beach.

Interviewees	Activities on the beach				Number of visits (times/year)	
	Swimming	**Sitting and relax**	**Fishing**	**Others**	**1-2**	**>2**
Local Tourists	6	15	-	2	10	21
Entrepreneur (Grocery/Resort/Construction)	-	10	5	2	-	13
Agriculture (Rice/Shrimp farm/Horticulture/ Palm/Vegetables/Fishery)	2	11	3	3	-	8
Official	4	6	-	4	-	20
Others (Employees etc.)	10	11	-	6	10	18
Total	22	53	8	17	20	80

Changes in residence in the community:

The density distribution and increases in the communities along the coast were evaluated using LANDSAT satellite in 1999-2011 and THAICHOTE in 2012.Analysis of the community distribution found the community increased since 2004 and in the northern area of the beach there was some relationship between increases in the urban area and coastline change within 50 m of the shoreline. In contrast, in the central and southern areas of the beach, population increases affected coastline change within 50-100 m of the shoreline (Figures 65 and 66).

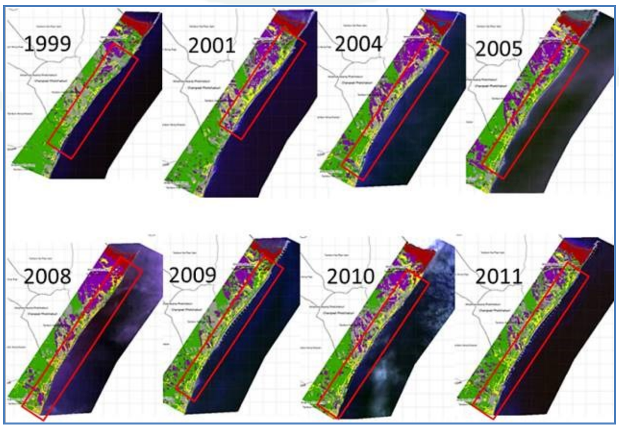


Figure 65 Community density (yellow area) along the coast of Chao Samran during 1999–2011 has increased continuously since 2004

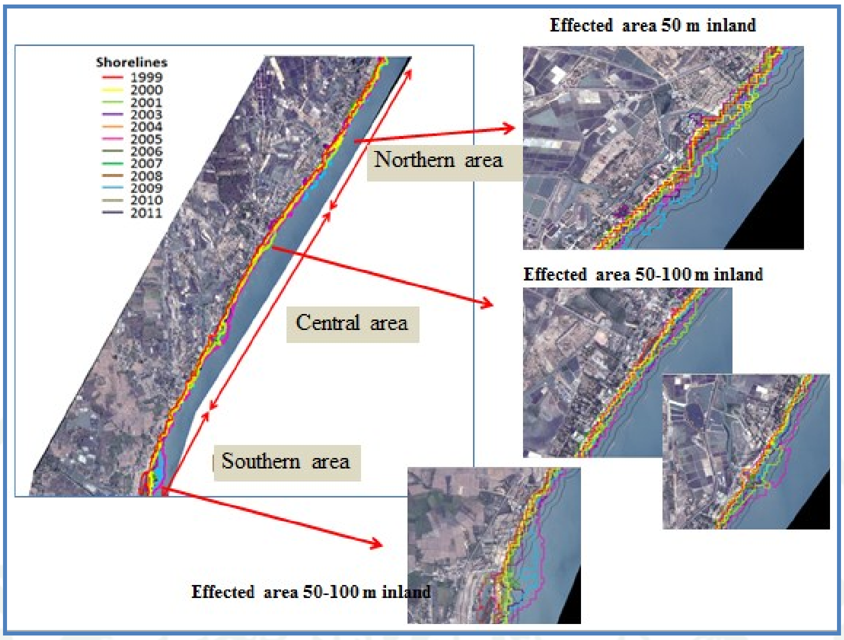


Figure 66 Shoreline changes during 1999–2011 and showing effected area at 50-100 m along the beach.

Density increased according to the economic and social development plan of the municipal district, which has three main priorities: 1) urban and infrastructure development, 2) support of investment, commerce, and tourism, and 3) management and development of natural resources and the environment (Hat Chao Samran Municipal District, 2012).

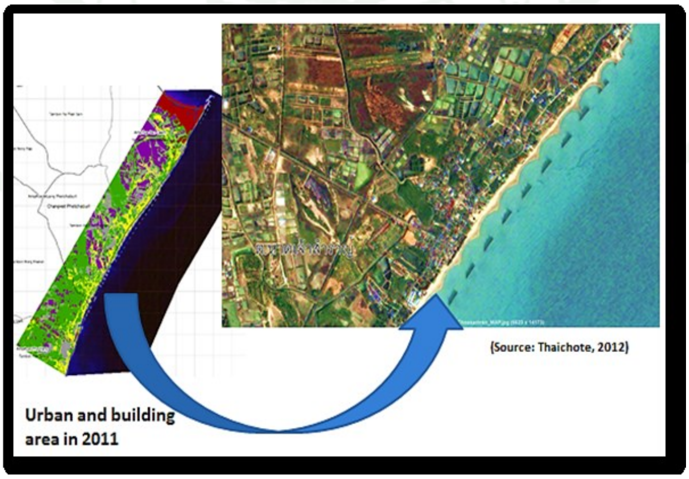


Figure 67 Expansion of infrastructure and communities near the beach area derived THAICHOTE in 2012

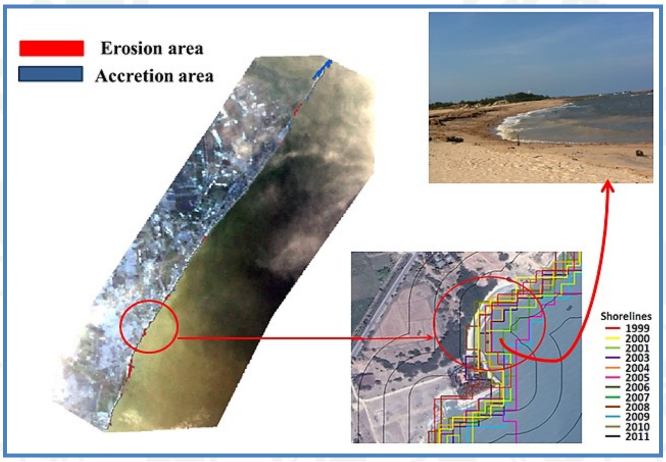
In summary, the analysis of the social impact of erosion and accretion focused on the potential need for resettlement and safety zone for the residential. Analysis of the community distribution found the community increased since 2004. Density increased according to the economic and social development plan of the municipal district, which has three main priorities: 1) urban and infrastructure development, 2) support of investment, commerce, and tourism, and 3) management and development of natural resources and the environment. With this development plan is consistent with the change of land use to increase revenue, the increase in population, the development of infrastructure to support tourism, including measures to solve environmental problems in the area. There was also some relationship between increasing in the urban area and the coastline change. In the central and southern areas of the beach where the urban area had the most increasing, the coastline changed radically and this affected community or utilities within 50-100 m of the shoreline. It means the safety zone in the central and southern area is the area after 100 m from the shoreline. In contrast, in the northern area of the beach where there was the less urban and the most mangrove area, the coastline changed less, and this affected community or utilities within 50 m of the shoreline. It means the safety zone in the northern area is the area after 50 m from the shoreline. Also, refer to the results of relationship analysis between land use and erosion and accretion showed a decrease in the aquaculture and agriculture area, turning them into bare land and urban area, especially resort. This is reflects the changes of livelihood and traditional lifestyle, such as from an agricultural society to accommodate much more about tourism.

11. Economic Impact

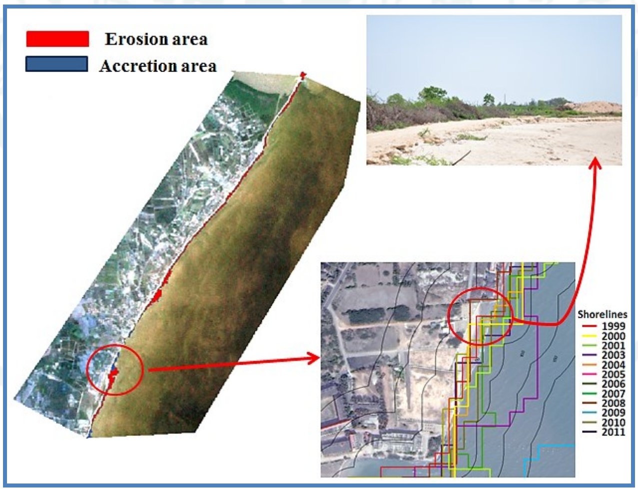
Economic impacts caused by erosion and accretion which obviously is losing the beauty of the natural beach, the negative impact on tourism in the area, the loss of land and infrastructure along the beach. The economic loss has affected both the beach owner and the government to spend more budgets to protect the beach in various measures, both effective and ineffective. The economic impacts were shown as following;

11.1 Value of threatened lands

The total threatened land obtained from the calculating of difference area between the average erosion and accretion area that derived from LANDSAT images during 1999 to 2011. The land prices were obtained from current market prices which based on the average prices quoted by real estate brokers. The market value was estimated at the current land price per square meter. The result is shown in Table 17.



-Fig. 68a-



-Fig. 68b-

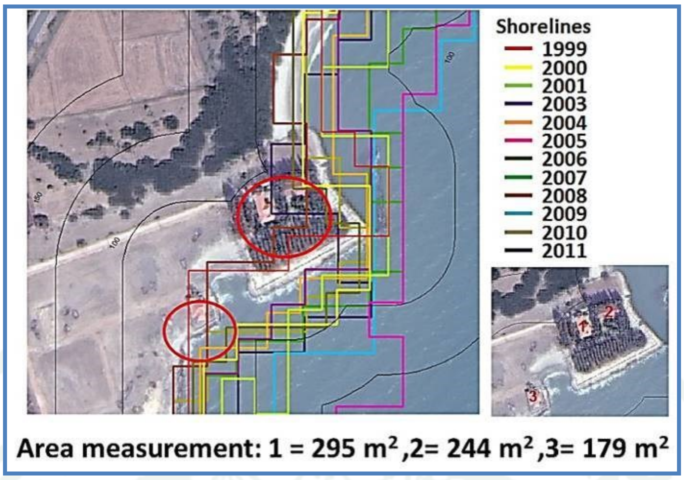
Figure 68 Threatened land (m^2) is shown on LANDSAT image in the red circle. The enlarge erosion area is a THAICHOTE image for 2012 provided by GISTDA and a photo of erosion area from field survey.

Table 17 The value of threatened lands (TVL)

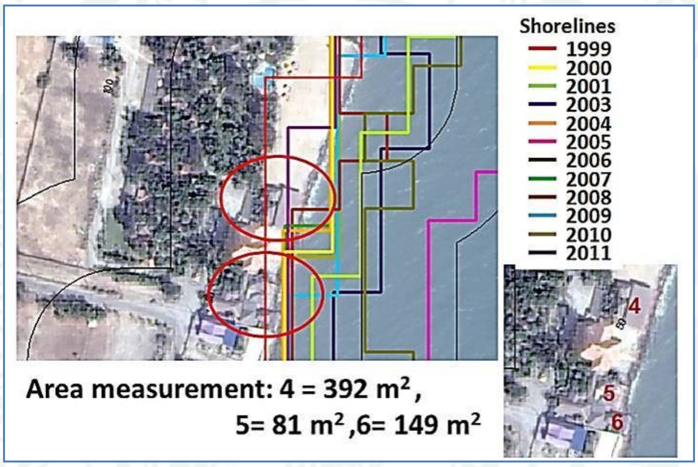
Year	Erosion (m^2)	Accretion (m^2)	Erosion Land price (3,644 Baht/m^2)	Accretion Land price (3,644 Baht/m^2)
1999 & 2000	267,696.45	173,750.77	975,485,849.90	633,147,788.48
2000 & 2001	23,989.92	1,023,186.83	87,419,281.67	3,728,492,803.86
2001 & 2003	326,520.23	202,240.78	1,189,839,730.44	736,965,400.66
2003 & 2004	981,929.99	46,794.22	3,578,152,882.03	170,518,147.76
2004 & 2005	36,216.75	1,485,031.45	131,973,841.28	5,411,454,619.07
2005 & 2006	1,355,846.71	59,552.82	4,940,705,398.74	217,010,483.14
2006 & 2007	335,399.41	179,893.78	1,222,195,447.01	655,532,931.61
2007 & 2008	244,601.35	276,571.82	891,327,321.98	1,007,827,700.01
2008 & 2009	32,846.17	1,472,598.28	119,691,459.61	5,366,148,140.85
2009 & 2010	1,377,991.07	160,185.75	5,021,399,463.45	583,716,879.48
2010 & 2011	289,895.70	622,085.99	1,056,379,943.90	2,266,881,362.62
Average	488,924.89	422,638.88	1,781,707,891.20	1,612,976,078.70
Threatened land (m^2)		168,731,812.50		

11.2 Value of threatened buildings and structures

The analysis of damage on property values (buildings and infrastructure) was done by investigation threatened building and structures on land at approximately 150 m from the shoreline. The threatened property were calculated by using the time series of shoreline vectors that derived from LANDSAT images during 1999 to 2011 and superimposed on high resolution satellite images (Quickbird 2009 with 0.6-m resolution). The threatened property defined as buildings or structure that located in eroded shoreline during 1999 to 2011 and confirmed the damage of property by interviewing the local people. Only threatened buildings found in this study area. The size of threatened building was measured from QUICKBIRD image. The property prices were obtained from the Department of the Treasury. The damage value is shown as Table 18.



-Fig. 69a-



-Fig. 69b-

Figure 69 Buildings and structures threatened by shoreline erosion are shown in the red circle; the base map is a THAICHOTE image for 2012 provided by GISTDA

Table 18 The value of threatened Buildings (TVBS)

Properties	**Buildings and Structures threatened (m^2)**	**Buildings and Structures Price**[(2)] **(Baht/ perm^2)**	**TVBS (Baht)**
1 Single story/ Two-story/ Three story commercial building	1,161	6,750	7,836,750.0 0.98
2 Single and two story houses.	179	6,250	1,118,750.0
Total (Baht)			8,955,500.0

11.3 Value of social services from threatened beaches

The primary natural resources at risk along Hat Chao Samran are the sandy beaches. Beaches provide important regulatory, ecological, and economic functions. They also serve as habitats for diverse biological species and provide recreational services.

It was nevertheless important to still include the value of the beaches in the analysis considering the benefits and services that they provided as well as the potential impacts of some coastal erosion adaptation options on them. From the site visits and interviewing (Table 20) that the researcher conducted, the uses of the beach along Hat Chao Samran was identified for recreation such as picnics, sitting and jogging by residents in Petchaburi province and nearby.

Annual Recreational Value of Beaches = E*S*V*P = E*V*P
= 400 * 53 * [80*12*(6/24)]
= 5,088,000 Baht

Where

E = Expense per person per day = 400 Baht

S = Shadow Exchange Rate (SER) = no exchange rate due to using Thai Baht

V = Percent of visitor utilized the beach for recreational purpose = 53%

P = The respondents visited the beaches an average of two days per 2 months for about six hours per day
= Coastal population of 80* 12 days * (6 hours/24 hours)

In summary, the economic impact of the study area focused on the loss of land and infrastructure along the beach. The economic vulnerability (EV) that occurred in the area during 1999-2011 affected both the beach owner and the government to spend budgets to protect or repair the beach and their properties much more. Value analysis of the threatened land by calculating a marketable price is equal to 168.7

million baht. Furthermore, the investigation of threatened building and structure found only the threatened building. The value of threatened building was evidenced damages by analyzing the building is in an area that had critical shoreline change and interviewed people in the area. The total damage of building is approximately 8 million baht. In addition the Value of social services from threatened beaches in term of annual recreational value of beaches is equal 5.08 million baht. The calculation of economic vulnerability for the past 15 years on this study area was about 182.8 million baht, mainly in the middle and the south of the study area. The result is shown as Table 19.

Table 19 Current value of land (TVL), buildings, and structures (TVBS) threatened by shoreline erosion during 1999–2011.

Properties	Threatened Area (m^2)	Land price [1] (Baht/ per m^2)	Buildings and Structures threatened (m^2)	Buildings and Structures Price[2] (Baht/ per m^2)	TVL (Baht)	TVBS (Baht)	Social services
1.Land threatened							
1.1 Erosion area (-)	488,942.89	3,644			1,781,707,891.2	488,942.89	
1.2Accretion area (+)	442,638.88	3,644			1,612,976,078.7	442,638.88	
2.Buildings and Structures threatened							
2.1 Single story/ Two-story/ Three story commercial building			1,161	6,750		7,836,750.0 0.98	
2.2 Single and two story houses.			179	6,250		1,118,750.0 0.04	
3 Value of social services from threatened beaches							
					168,731,812.4	8,955,500.0	5,088,000
Total (EV)							182,775,312.40

[1] Maketable price during 2012-2015 from http://phetchaburi.homeland4sale.com/landprice.php andhttp://www.teedin108.com/land/view/361370/

[2] Land price referenced from Department of Treasury in 2013 http://property.treasury.go.th/pvmwebsite/

Coastal Risk Mapping

1. Sensitivity index for coastal erosion

Oceanographic buoy data (1993–2006), meteorological data (1999–2011), and field data (2012–2013) described in sections 5.1were analyzed and categorized using threshold criteria and categorized by applying the risk scoring approach of the Eurosion project in 2004. Maximum values for wind, wave, and current data from each source for each year were determined and tabulated.

For land use, scoring was conducted using a spatial regression technique (GWR) for land use type, erosion, and accretion. The maximum coefficient value from spatial regression analysis was input for this prioritized scoring system.

Table 20 The severity of natural and anthropogenic factors affecting coastal zone changes in the study area.

Parameters	Critical	Medium	Low
1.Season	2^{nd} inter monsoon (Sep-Oct)	NE monsoon (Nov-Jan)	SW monsoon (May-Aug)
2.Wave (m)	>2	1-2	>1
3.Wind (m/s)	>20	13-20	>13
4.Current (cm/s)	>60	40-60	>40
5.Land use	Urban area	Aquaculture	Agriculture area
6.Erosion (Km^2)	>1.3	0.5-1.3	>0.5
7.Accretion area (Km^2)	>1.4	1.0-1.4	>1.0
8.Erosion rate (m/yr)	>5	1-4.99	0-0.99

Table 21 Parameters frequency during 1999–2011 based onthe maximum value.

Year	Wind speed (m/s)	Wind direction (season)	Wave height (m)	Current speed (cm/s)	Current direction	Mangrove	Aquaculture	Agriculture	Bare land	Urban and building
1999	10,8	SW, NE	1.5,NE	62	2nd	0.155338	0	0	0	0
2000	12,5	2nd, SW	1.5,SW	60	SW	0.015517	0	0	0	0
2001	14,4	2nd,NE	1,SW	100	SW	0.122743	0	0	0	0
2002	14,5	NE,SW	2.1,NE	80	NE	0	0	0	0	0
2003	6	NE	0	42	NE	0	0	0	0	0.099743
2004	6	NE	0			0	0	0	0.090907	0
2005	13,8	NE,1st	1.7,2nd	70	2nd	0	0	0	2.416977	0
2006	15,25	NE,NE	2.3,NE	80	NE	0.196092	0	0	0	0
2007	7	NE	-	-	-	0	0	0	0	0.008077
2008	8	NE	-	-	-	0	0.017777	0	0	0
2009	7	NE	-	-	-	0	0	0	1.407886	0
2010	6	NE	-	-	-	0	0.039549	0	0	0
2011	6	1st & NE	-	-	-	0	0	0	0	0

Data sources:

1) Wind, wave, and current data from SEAWATCH buoy and meteorological data.
2) Five land use types based on the coefficient values of GWR/OLS.

To calculate the severity indices and determine the risk categories, variables were established as follows:

Parameter	=	Historical parameter affecting coastal zone change during 1999–2011
Frequency	=	Number of maximum values for each parameter during 1999–2011
Weighting	=	Potential magnitude of damage (e.g., low, medium, high)
Area impact	=	The coastal area affected by erosion or accretion

The individual criteria were evaluated and analyzed to establish risk categories for coastal erosion and accretion. A scoring system was then used for the overall analysis as shown in Equation 9. The data in Table 21 were used to score the sensitivity indices affecting coastal zone change during 1999–2011. The relative priority scoring system is shown in Tables 22–24.

Table 22 Scoring of severity indices affecting coastal zone change during 1999–2011.

Criteria	Frequency during 1999-2011	Weighting
1. Season		
NE monsoon	12	3
Transition period	4	2
SW monsoon	3	1
2. Wind speed		
>20 m/s	3	3
10.1-20 m/s	5	2
0-10 m/s	8	1
3. Wave height		
>2 m	3	3
1.1-2 m	3	2
0-1 m	1	1
4.Current speed		
>60 cm/s	4	3
30-60 cm/s	4	2
0-30 cm/s	0	1
5.Land use		
Urban and building	2	2
Aquaculture	2	3
Agriculture	0	1
Bare land	3	2
Mangrove	4	3

Table 23 Relative priority of risk categories.

Risk category	Potential Damage Magnitude (Weighting)	Area Impact
Low	1	0-0.5 Km^2
Moderate	2	0.6-1.3 Km^2
High	3	>1.3 Km^2

Table 24 Establishment of risk categories.

Criteria	(Frequency +	Area impact)	x Magnitude =	Total
1.Season(Wind direction)				
1.1 NE monsoon	12	1.3	3	40
Transition period	4	1.2	2	10
SW monsoon	3	0.5	1	4
2.Wind speed				
2.1 Wind speed>20 m/s	3	1.3	3	13
2.2 Wind speed10.1-20 m/s	5	1.2	2	12
2.3 Wind speed0-10 m/s	8	0.5	1	9
3. Wave height				
3.1 Wave height >2 m	3	1.3	3	13
3.2 Wave height 1.1-2 m	3	1.2	2	9
3.3 Wave height 0-1 m	1	0.5	1	2
4. Current speed				
4.1Currentspeed>60 cm/s	4	1.3	3	16
4.2Currentspeed30-60cm/s	4	1.2	2	10
4.3Currentspeed0-30 cm/s	0	0.5	1	1
5. Land use				
5.1 Urban and building	2	1.2	2	6
5.2 Aquaculture	2	1.3	3	10
5.3 Agriculture	0	0.5	1	1
5.4 Bare land	3	1.2	2	8
5.5 Mangrove	4	1.3	3	16

From table 24 could be summarized the scoring of sensitivity indexes affected to coastal zone change during 1999-2011 as following;

Table 25 Criteria for risk area mapping based on historical data for 1999–2011.

Physical criteria	Risk level	Considering criteria
1. Erosion rate	3	-Erosion rate > 5 m/yr.
	2	-Erosion rate 1- 5 m/yr.
	1	-Erosion rate <1 m/yr.
2.Wind direction	3	- NE monsoon
	2	- Transition period
	1	- SW monsoon
3.Wind speed	3	- Wind speed >20 m/s
	2	- Wind speed 10.1-20 m/s
	1	- Wind speed 0-10 m/s
4.Wave height	3	- Wave height >2 m
	2	- Wave height 1.1-2 m
	1	- Wave height 0-1 m
5. Current speed	3	- Current speed >60 cm/s
	2	- Current speed 30-60 cm/s
	1	- Current speed 0-30 cm/s
6. Land use	3	-Mangrove
	3	-Aquaculture
	2	- Urban and building
	2	- Bare land

Table 26 Sensitivity indices for coastal zone change during 1999–2011.

Risk level	Sensitivity indexes
High (3)	-Season (NE monsoon)
	-Wind speed >20 m/s
	-Wave height >2 m
	-Current speed >60 cm/s
	-Mangrove
	-Aquaculture
	-Erosion rate > 5 m/yr.*
Medium (2)	-Season (Transition period)
	-Wind speed 10.1-20 m/s
	-Wave height 1.1-2 m
	-Current speed 30-60 cm/s
	- Urban and building
	- Bare land
	-Erosion rate 1- 5 m/yr.*
Low (1)	-Season (SW monsoon)
	-Wind speed 0-10 m/s
	-Wave height 0-1 m
	-Current speed 0-30 cm/s
	- Agriculture
	-Erosion rate <1 m/yr.*

2. Risk mapping

To map the risk of coastal zone change in the study area, spatial analysis in ArcGIS was used. Each physical criterion from Table 26 was reclassified into three risk levels consisting of high, medium, and low risk. To generate the risk map for the area, coastal vulnerability was analyzed by adding the scores together to create summary scores for each location in the area. These summary scores of wind speed, wind direction (season), wave height, current velocity and direction, land use, and erosion rate were used to develop a summary risk map (Figure 70).

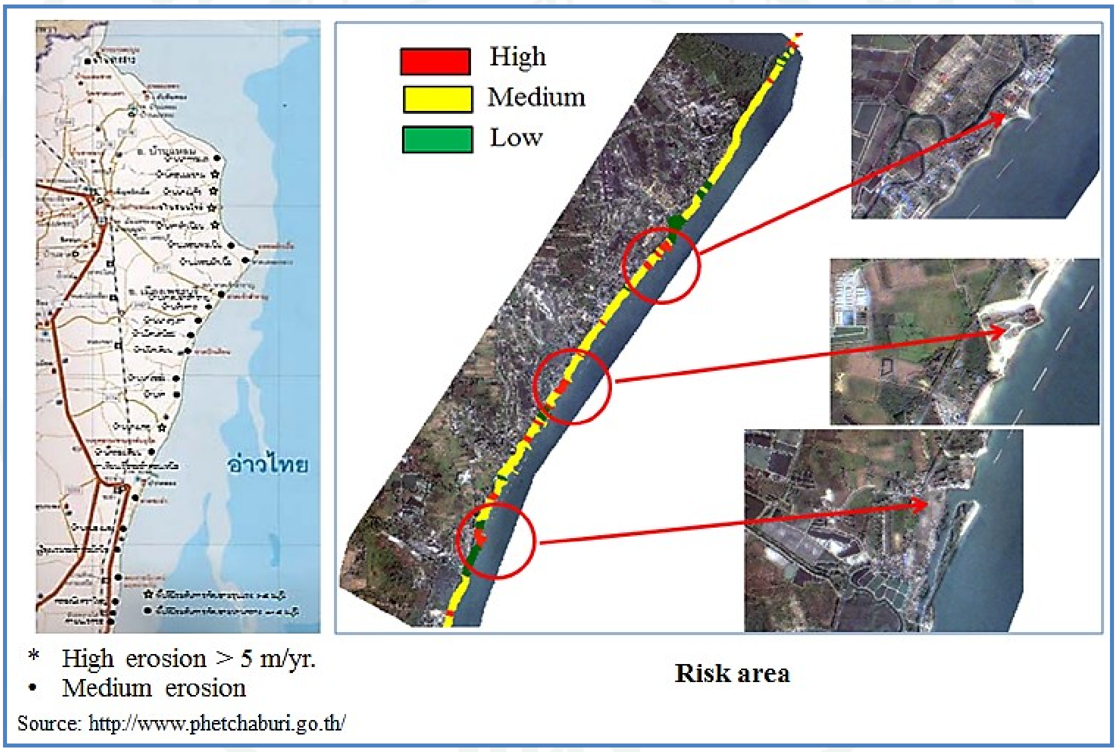


Figure 70 Risk area based on sensitivity indices along the study coast

Using sensitivity indices including wind speed, wind direction (season), wave height, current velocity and direction, land use, and erosion rate found along the coast in the study area, the analysis determined that most areas had medium vulnerability to change (erosion 1-5 m/yr.), except the central, southern and some part of the north area, which was high vulnerable (erosion >5 m/yr.) to coastal changes. The low risk analysis also found along the coast. If we considerate the sensitivities indices as Table

26 showed that the mangroves and aquaculture to be at high risk and urban and bare land to be at medium risk but the composition of other factors on the spatial analysis might be incomplete, so the risk is reduced. If compared to the severity level of erosion area from the risk map of Petchaburi province (cited in http://www.phetchaburi.go.th). It was consistent that the most area was medium vulnerability. Furthermore, it was found that the sensitive area due to the topography of this area has a long, straight sand beach oriented north-south and directly affected by seasonal monsoons, which are one of the natural forces causing coastal erosion

Spatial Modeling

Integrated spatial modeling was conducted that combined the physical and socioeconomic risks. The risk level of each factor, the physical, social and economic analyzed using spatial risk level and overlay technique. The physical risk described in Section 5.3, social and physical risk through the process of converting format layer to rater, reclassify and cell statistics. Then the analysis was carried out using ModelBuilder in ArcGIS. These risk maps can be classified as follows:

1. Physical risks map included the erosion risk from Table 26 :
   - High risk: high erosion risk area
   - Medium risk: moderate erosion risk area
   - Low risk: low erosion risk area

2. Social risks map included residences, communities, and land use from Table 26:
   - High risk: 0–50 m from the shoreline
   - Medium risk: 50–100 m from the shoreline
   - Low risk: >100 m from the shoreline

3. Economic risk map included loss of land (erosion) and damaged buildings over the past 12 yr from Table 26 and the level of economic loss is based

on losses of land, building and structure, and social services in the critical erosion area:

- High risk: damage >100 million baht
- Medium risk: damage 51–100 million baht
- Low risk: damage <50 million baht

In summary, the risk level could be categorized into 3 levels as following:

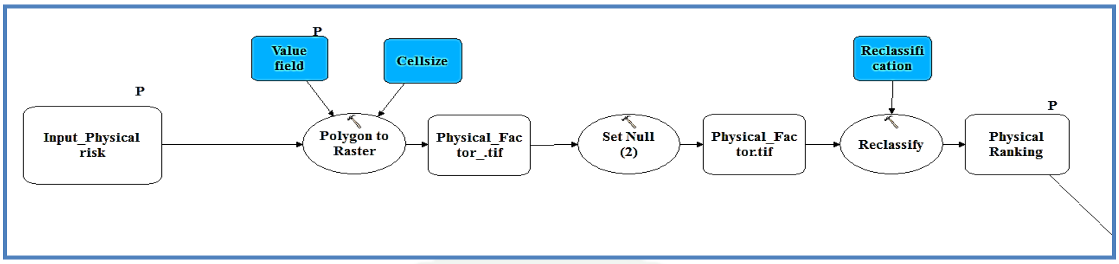
High risk (3):	- High erosion risk area - Social risk 0–50 m from the shore - Damage> 100 million baht
Medium risk (2):	- Moderate erosion risk area - Social risk 50–100 m from the shore - Damage 50–100 million baht
Low risk (1):	- Low erosion risk area - Social risk >100 m from the shore - Damage<50 million baht

1. Preparation of input data

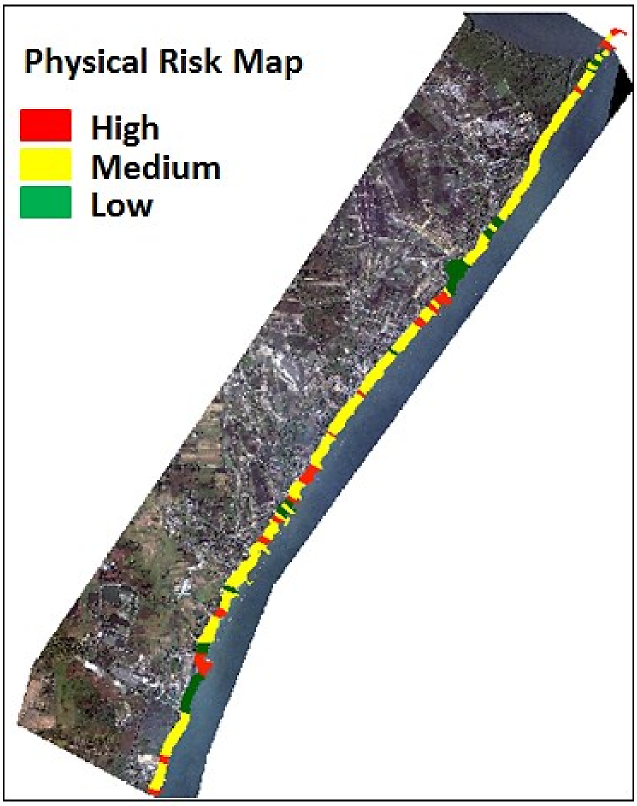
There are three layers consisting of physical, social and economic risk map were prepared to be input data of the spatial model. The results are shown below:

1.1 Physical risk map

Spatial data set of erosion risk map includes erosion and accretion area and erosion rate was prepared by the procedures of making polygon and line to raster, specified criteria (set null) and reclassify output value using ArcToolbox in ArcGIS. The steps and output are shown as Figure 71.



-Fig. 71a-

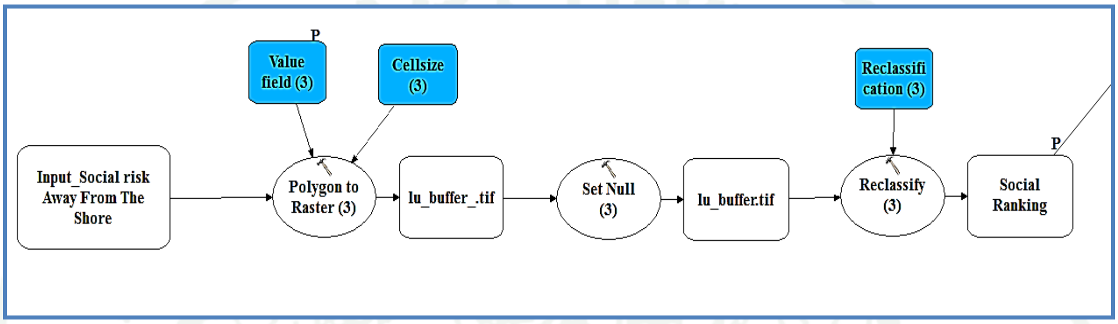


-Fig. 71b-

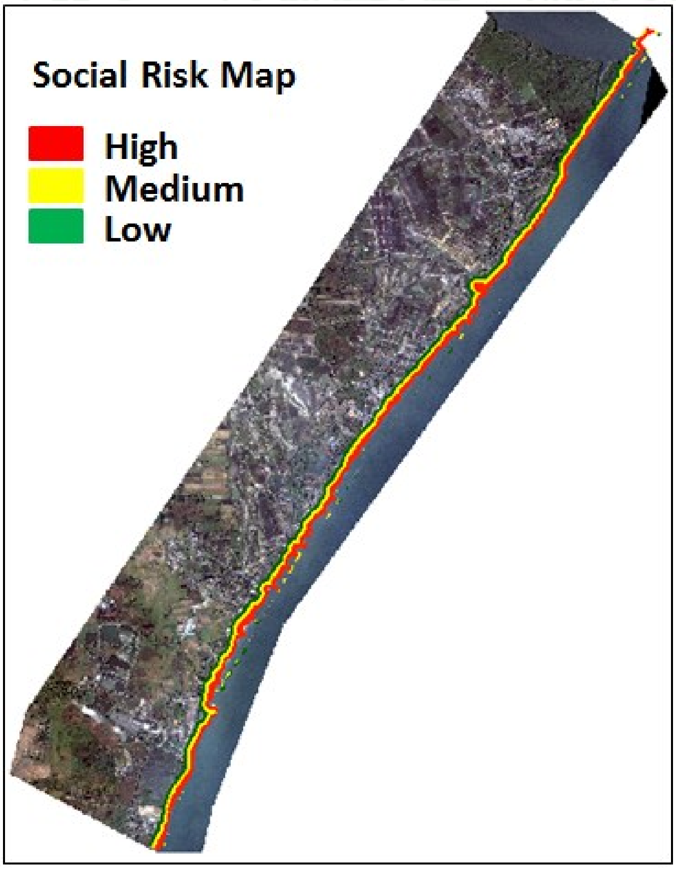
Figure 71 Preparation of data for physical risk map

1.2 Social risk map

All layers include settlement of communities and land use was prepared using ArcToolbox in ArcGIS. The geoprocessing includes making polygon to raster, specified criteria (set null) and reclassify output value. The steps and output are shown as Figure 72.



-Fig.72a-

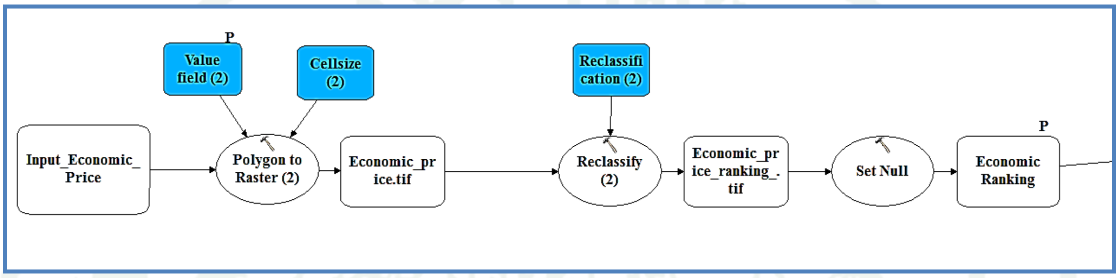


-Fig 72b-

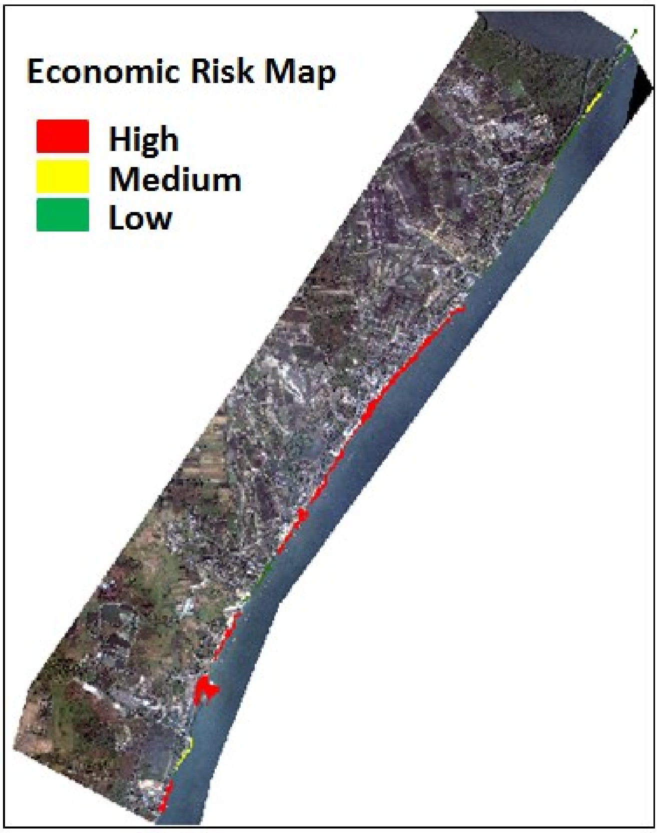
Figure 72 Preparation of data for social risk map

1.3 Economic risk map

Economic risk included loss of land (erosion) and damaged buildings along the beach were prepared using ArcToolbox in ArcGIS. The procedures include making polygon to raster, specify criteria (set null) and reclassify output value. The steps and output are shown as Figure 73.



-Fig. 73a-



-Fig 73b-

Figure 73 Preparation of data for Economic risk map

2. Developing the spatial model

2.1 Constructing the new model

A spatial model for long-term coastal zone change was constructed using Model Builder in ArcToolbox of ArcGIS, this operation is geoprocessing with can help to solve geographic problem and responsible for carrying out the same analysis for several areas or scenarios. The first step to develop the model was exploring the toolbox in ArcGIS. Due to ModelBuilder is a graphical user interface (GUI) application, we could point to Geoprocessing menu click access to ArcToolbox and then add new toolbox.

2.2 Environment for accessing tools

The second step was done for setting up the environments accessing tools. The output features as physical, social and economic risk map from 5.4.1 was added into the model. Then we set up tools to run in a given sequence, using the output of one tool as input to another tool. Within this toolbox we clicked Spatial Analyst Tool and selected Conversion Tool to converse each polygon to raster. From each raster we did select 3D Analyst Tool, raster reclass and reclassify tool in order to reclassify the raster and specify criteria for each risk level. Then the Conditional Tool (Set Null) was used to group the unclassified value. Each process was connected by linking the output of one process to the input of another using the connection tool.

2.3 Running the model

The model was saved and run using its graphical user interface (GUI) window. When the model finished running, the output was as Figure 74. The output provided in both graphic (*.png) and phyton script. Then we could have spatial model for long-term coastal zone change as Figure 74.

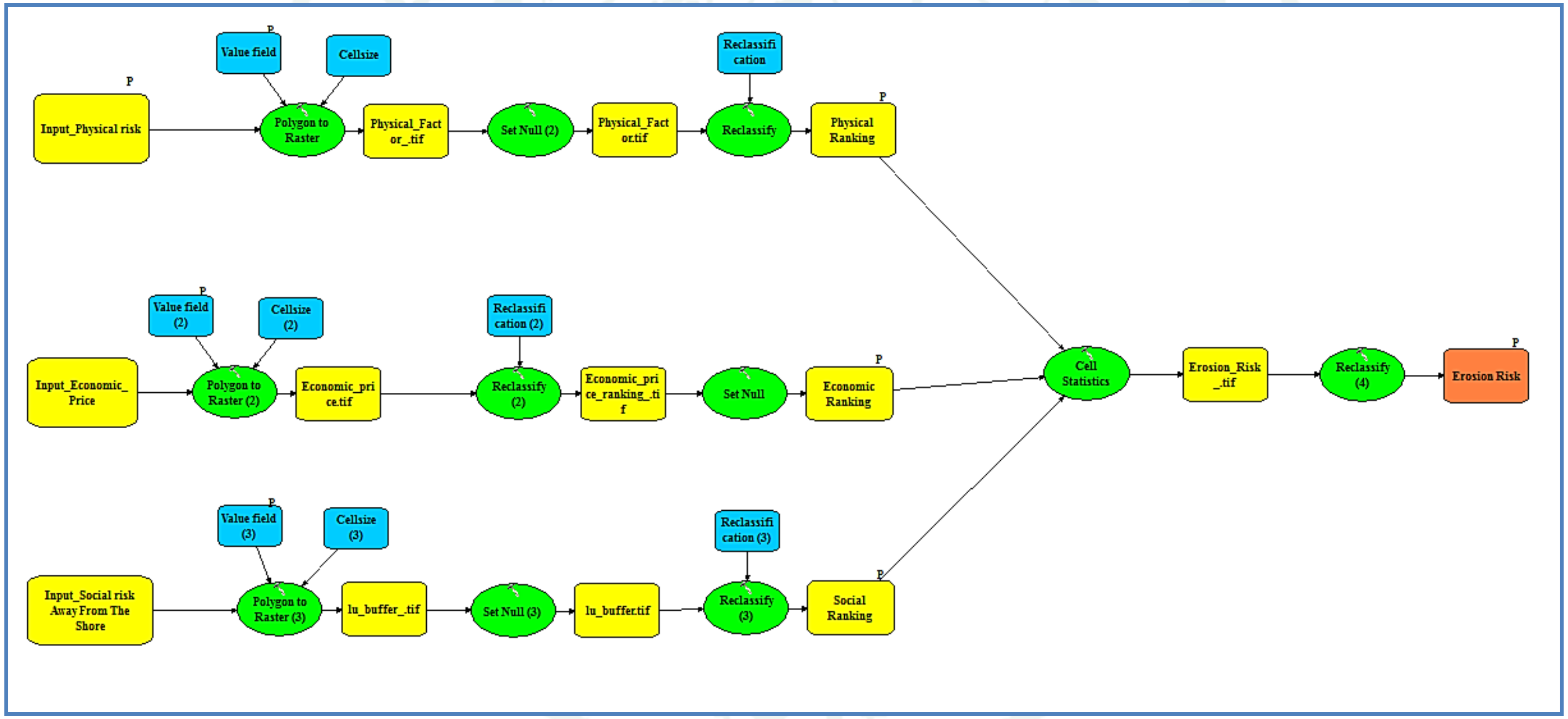


Figure 74 Diagram of a geo-processing linear feature model to develop of spatial modelling for a long-term erosion risk map.

2.4 Spatial model for coastal zone change

The risk map of Hat Chao Samran beach analyzed by using a spatial model which integrated features both the physical, social and economic impact during 1999-2011 and running with ModelBuilder in ArcGIS 10.1 as a procedure in Fig.74. It was found that the high risk areas were mostly in the central and southern area at a buffer of 50 meters from the beach. In addition, it also found a bit area of high risk at a buffer of 50 m from the beach in the north area. A medium risk area located at a buffer of 50-100 meters along the beach. The same as the low risk area found also at 150 meters from the beach.

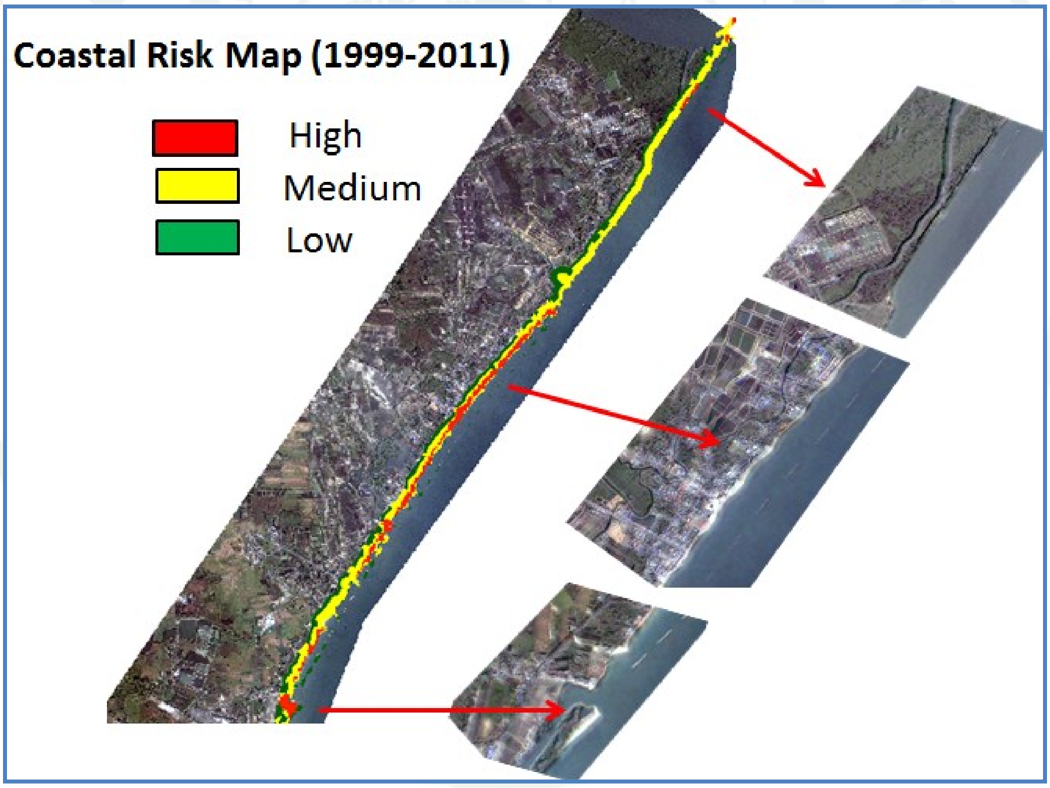


Figure 75 Spatial coastal risk map analyzed by integrating physical, social and economic risk during 1999-2011

3. Model testing

To test whether the spatial coastal risk model using the data set during1999-2011 able to run with the other scenarios, so it was done repeating scenario using the data set before breakwater construction during 1999-2006 and data set after breakwater construction during 2009-2011.Results of the comparison between the three periods were as Figure 76.

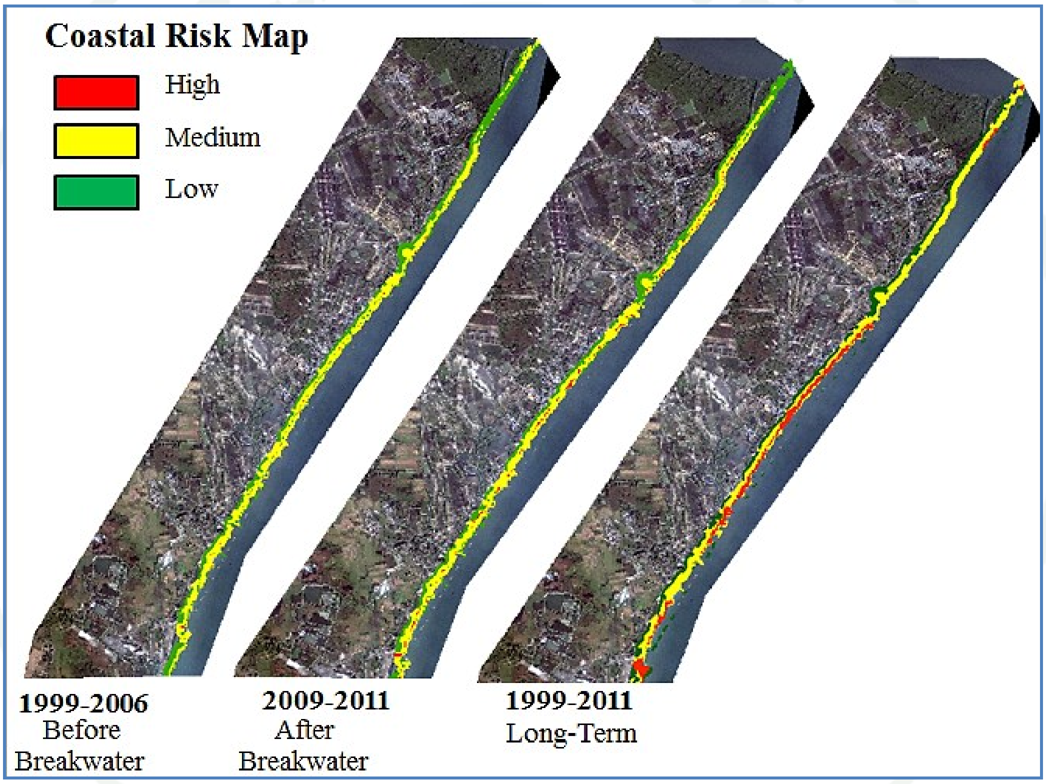


Figure 76 Spatial coastal risk map analyzed by integrating physical, social and economic risk during 1999-2006 (Before breakwater construction), 2009-2011 (After breakwater construction) and the whole period (1999-2011).

Table 27 Comparison between the several scenarios in risk areas.

Scenarios	Risk areas (Km^2)		
	Low	**Medium**	**High**
1.Long-term spatial model (1999-2011) with integrating physical, social and economic impact	0.90	1.3	0.49
2.Spatialmodel before breakwater construction (1999-2006) with integrating physical, social and economic impact	1.16	1.52	0.01
3.Spatialmodel after breakwater construction (2009-2011) with integrating physical, social and economic impact	1.09	1.51	0.09

In summary, the risk to the Hat Chao Samran beach analyzed by using a spatial model which integrated features both the physical, social and economic impact during 1999-2011 and running with ModelBuilder. Model testing showed different result in three scenarios. It found that the high risk area from long-term scenario (1999-2011) in the same area as before breakwater scenario (1999-2006) and after breakwater scenario (2009-2011) but more high risk area than those two scenarios. It was found that the high risk areas were mostly in the central and southern area at a buffer of 50 meters from the shoreline in the central and southern areas, particularly within the estuary. The output of spatial model for long-term coastal zone change provided in both graphic (*.png) and phyton script. The use of ModelBuilder for this spatial model can provide automatic model for carrying out the same analysis for several areas and scenarios.

Discussion

1. Factors affecting to coastal zone change at Hat Chao Samran

The topography of Hat Chao Samran is straight and trending in a north - south. Therefore, the factors affecting to the coastal area during the last 15 years was the influence of the natural factor, especially the NE monsoon and 2^{nd} inter transition period which was the most influential factor in the study area during the period prior to the construction of a breakwater (1999-2006). These monsoon periods affected the variability of wind-wave, which influence the occurrence of erosion and accretion during this period. But after a breakwater construction (2008-2013), which is a human activity that was created in 2008 in order to protect the beach and the influence of the breakwater had a pronounced effect on the accretion and erosion in the area since 2008. This structure affected the balance of sediment and reduced the strength of waves and currents. Coastal sediment transport caused by waves and currents, tides, and wind (Satumanatpan, 2012). This is consistent with studies of Sarajit and Nakhapakorn (2014) which showed that the difference during monsoon had an indecisive difference effect on shoreline changing of Petchaburi. However, the influence of the monsoon had effected to the beach sediments in sandy beach; the lower zone of Petchaburi. The sand sediment increased in the. Southwest monsoon and decreased in the Northeast monsoon.

Furthermore, the analysis of the factors that caused by human activity, spatial analysis techniques was introduced for the relationship between the type of land use, erosion and accretion. The result expressed that the land use types which located near the beach about 50-100 meters affected the most critical erosion and accretion. The land use types that had the most influence to erosion, was urban and building area, aquaculture, bare land and mangrove, respectively. And land use types that had the most affect to accretion was urban and building area, aquaculture, and mangrove, respectively. For agriculture and rice field were planted about 1-2 km from the sea, it did not affect the coastal areas. This complies with the strategies plan to prevent and solve the coastal erosion problem which stated that the development of coastal areas and the expansion of the city as well as the development or expansion of infrastructure is all about land use change on coastal areas in different ways. These caused the loss of the coastal equilibrium and they were a major factor of changes in coastal areas (DMCR, 2008; The Office of Natural Resources and Environment Policy and Planning, 2009).

2. Impacts of coastal zone change

Physical change in term of erosion and accretion at Hat Chao Samran for the past 15 years were studied with the use of satellite imagery analysis and found the severe erosion and accretion in two periods; the critical erosion was between 2005-2006 and 2009-2010 and the critical accretion during 2004-2005 and 2008-2009. Additionally, the severe erosion during the years 2005-2006 was probably the cause of the measures to prevent beach erosion. The breakwaters have prevented the beach erosion in the central area of Hat Chao Samran. Considering the beach area as a whole, the analysis of each year, found that although the structure protected since 2008, but also showed erosion and accretion in the lower part of Hat Chao Samran. Generally, the area showed that the southern area had the most severe erosion rate of more than 5 m / yr, followed by the central area with an erosion rate of 0-4.9 m / yr and an accretion rate of 1-10 m / yr. The northern area had a high accretion rate of over 10 m / yr. (Figure 52). The rate of change in different parts of the coastal area was markedly consistent with the land use types since the upper part of the area covered by the mangrove, thus affecting the coastal sediment traps while the middle and lower part had the growth of the community and breakwater to protect the beaches. Therefore, the hard structure even helped to prevent beach in problem areas, but also raised the issue in the neighbor area. The effect of breakwater caused critical erosion and accretion since 2008. Before breakwater construction, the results of this study found low erosion and accretion condition in each year and approximately 6 years showed severe erosion and accretion. But after breakwater construction, approximately 4 years showed severe erosion and accretion as table 11. The results as in Table 11 found that critical area between the years 2005-2006, causing a breakwater built in 2007-2008. So if relevant agencies considered to use a long-term data for the erosion protection measures, it should be other proper protections instead of building a breakwater to prevent the beach but caused also the problem to adjacent area. Therefore, the measures taken to resolve such issues may not be sufficient to comply with the issue or area. Measures should be integrated with other appropriate solutions in order to achieve more sustainable and fix the problem without affecting other areas. This is consistent with studies of Rattanamanee, Limjirakhajorn and Chotikasathien (2008) found that hard solution applies coastal structures, called as "structural method", to protect the beaches. Breakwater, groin, seawall and headland are typically used in shoreline protection. Hard solutions are generally appropriate for chronic and severe erosion sites. These measures are fully effective to the problem areas, but cause erosion to adjacent areas. Therefore, other alternatives or soft solutions with more reasonable and consideration of the study using a long-term data will enhance an understanding of beach system in problem area and lead to select a sustainable solutions.

In addition, the physical changes that occurred to the coast, affecting socio-economic impact of the communities in study area. The social impact on the security of the settlements, the results of the analysis showed that the upper part of the area was safe in after 50 meters of the coast line, middle and bottom area secured in the 50-100 meters from the coast line. From the analysis of settlements and livelihoods along the coast in the last 15 years, with an analysis of LANDSAT and THAICHOTE satellite images found settlements (Figure 67 and 69) was likely to approach the beach to accommodate the expansion of tourism and experienced a change of agriculture area increasingly such as aquaculture, rice field switched to resort and tourism infrastructure. In addition to the problem of coastal erosion in the Hat Chao Samran, the quality of coastal environment was still in good condition, the cost of travel was also very affordable and convenient transportation. Thus, the tourism in this area expanded rapidly, and these factors drove and reflected the changing lifestyles of traditional agricultural community into the tourism industry. But in the meantime, changes in livelihood and settlements made the picture of the beach invasion with land utilization along the beach as well. According to the study of Seepha (2010) said environmental quality index for beach tourism at Hat Chao Samran is 6.44 which is in medium to good level (3.5 stars) with medium water quality. However the important environmental issues are the beach erosion and invasion.

Considering the effects of the economic impact consists of damaged areas, buildings and structure damage and loss of social services for approximately $ 182.7 million baht. The damage effected to both the areas owner to repair their properties, and the government arranged the budget for beach protection, definitely since erosion spreading to the central and southern area. But on the other hand, this economic impact caused reducing in coastal land price while the protection measure rised up the coastal land price (http://www.cmprice.com/market). Therefore, economic factor was as well as the impact and additional factors in changes to the beach. The driving force to the economy of local communities is a very influential factor in determining measures and strategic management of the coastal area of Hat Chao Samran and many other coastal areas of Thailand.

3. Sensitivity index and risk mapping for Hat Chao Samran

The sensitivity indices in this study based on Geo-indicators consisting of monsoon, wave, wind, current, land use, erosion area and erosion-accretion rate. Each factors such as monsoon, wave, wind, current, erosion area and erosion-accretion rate were analyzed with the risk scoring approach, except the land use was analyzed using spatial regression analysis. The most recent study, using a weighting method based on interviewing the experts or stakeholders (Saaty, 1980; DMCR, 2011; Arunrat, 2008), which may cause some error. For this study is different from the past, because using the scoring parameters that measured the in situ data with multiple devices in near real-time and long-term more than 10 years. By weighting the severity of the area into 3 levels consisted of low, medium and high and analyzed the frequency of each parameter which measured during1999-2011, counted the parameter which was consistent with the erosion and accretion in the area. The results showed that the indexes influenced changes in the critical level, including NE monsoon, wind speed> 20 m/s, wave height> 2 m, Current speed> 60 cm/s, land use (mangrove, aquaculture) and. erosion rate> 5 m/yr. The sensitivity index ranking in each level was analyzed using overlay technique. In summary the most areas of Hat Chao Samran had medium vulnerability (erosion 1-5 m/yr.), except the central, southern and some part of the north area, which was high vulnerable (erosion >5 m/yr.) to coastal changes (Sarajit and Nakhapakorn, 2014; DMCR, 2012; DMR, 2008; West of the Environment Report , 2010-2011). The low risk analysis also found along the coast.

4. Risk area base on Long-term Spatial modeling

Management planning and measures to solve the coastal erosion problem need to know the basics data of the eroded area in physical, social and economic. Since a major problem with the most common statistical modeling technique and standard applications of regression when applied to spatial data is that the processes being examined are assumed to be constant over space. Therefore, analyzing the risk area due to changes in coastal areas with the long-term spatial modeling, which combined the physical and socioeconomic risk provided the risk area in more details consisting severe erosion area, the risk of settlement areas and affected area to economic losses. As opposed to recent studies, analysis of risk area emphasized only on physical factors, and provide details on specific eroded only (GISTDA, 2010; World Bank, 2007; Siripong, 2010. ; Thampanya et al., 2006; Sarajit and Nakhapakorn, 2014; DMCR, 2008; DMCR, 2012).

Table 27 Comparison of the risk map from physical base on Geo-indicators, social and economic impact and long-term spatial model

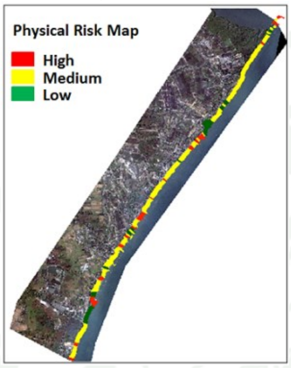
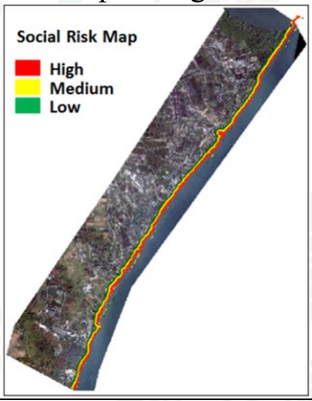
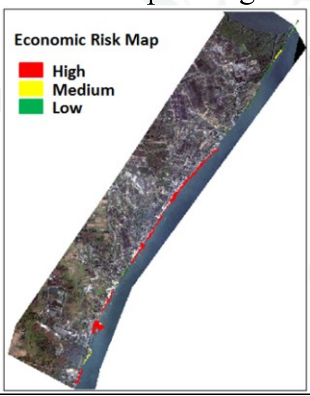
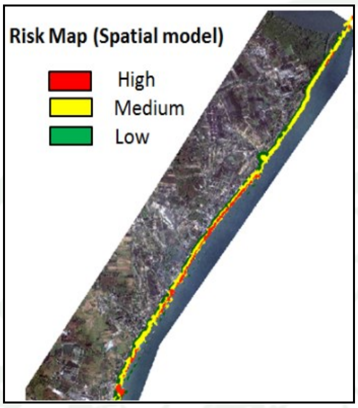
Factors	Risk area
1. Physical risk map (base on Geo-indicator during 1999-2011) 	Risk area are mainly distributed in the upper, middle and south. But overall, the study area was located at a moderate risk.
2. Social risk map during 1999-2011 	Risk area at Hat Chao Samran was mainly located along the coast between 0-50 meters from the coast, moderate risk within 50-100 meters from the shore and at a distance of more than 100 meters from the shores was low risk.
3. Economic risk map during 1999-2011 	Risk area at Hat Chao Samran was highly eroded areas in the central part and southern beaches and estuaries. Moderate risk areas was in the upper and middle slightly. The low risk areas was mostly in the upper part of the beach.

Table 27 (continued)

Factors	Risk area
4.Spatial risk map (combined physical, social and economic impact during 1999-2011) 	Risk area at Hat Chao Samran analyzed by combined physical, social and economic impact that the profile of high risk areas, and much eroding in the middle, some areas of the south, especially estuaries and some in the north at a distance of 0-50 meters from the shoreline. Medium risk area was along the coast at a distance of 50-100 meters from the shoreline, and the last is at low risk areas was over 100 meters onwards.

Upon the risk map analysis from spatial model was tested by input periods (Figure 78 and Table27). The result of model testing showed different result in three scenarios. It found that the high risk area from long-term scenario (1999-2011) in the same area as before breakwater scenario (1999-2006) and after breakwater scenario (2009-2011) but more high risk area than those two scenarios. This is because the long-term scenario has more data set. than other two scenarios. In addition, considering the effecting factors to the coastal zone change showed that in the period before breakwater was affected mostly from the natural factors, but the period later caused by anthropogenic activities such as breakwater and land use which had pronounced influence in high risk area. This caused before breakwater period had less risk area. Unlike the long-term scenario (1999-2011), this covers an obvious factor affecting both natural and man-made factor and provide a clear risk area than those two scenarios. The test model has argued that the use of spatial models for long-term coastal Hat Chao Samran provide a comprehensive spatial risk factors clearly related.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATION

Conclusions

1. Situation of coastal zone change at Hat Chao Samran

Hat Chao Samran, located in Petchaburi Province, has a total area of 19,445 km^2 and consists of seven villages with an approximate population of 4,500. The inhabitants work in five sectors: agriculture and aquaculture (farming and fishing), industrial, commercial, services, and tourism (Hat Chao Samran Municipal District, 2012). Data from the Petchaburi Provincial Statistical Office showed that agriculture is the main source of revenue; rice farming accounts for 59.29% of the total income generated, followed by tourism which accounted for 36.6%. However one of the main environmental issues in Hat Chao Samran is coastal erosion. Therefore, this study investigated the change of coastal zone for the past 15 years (1999-2013) with the use of satellite imagery analysis. In physical found the severe erosion and accretion in two periods; the critical erosion was between 2005-2006 and 2009-2010 and the critical accretion during 2004-2005 and 2008-2009. Generally, the area showed that the southern area had the most severe erosion rate of more than 5 m/yr, followed by the central area with an erosion rate of 0-4.9 m/ yr and an accretion rate of 1-10 m / yr. The northern area had a high accretion rate of over 10 m / yr. (Figure 52). Moreover the future shorelines were predicted over the short term (5 yr), medium term (10 yr), and long term (20 yr). The predictive shoreline model was determined to be as equation $Y = 1.214x - 1925.6$, $R^2 = 0.0216$. With using this model, by 2016, the distance between the baseline and the new coast line is predicted to be 521.824 m, a loss from 2011 of about 6.07 m. In another 10 years, the distance between the baseline and the 2021 coastline is predicted to be 527.894 m, a loss from 2011 of about 12.14 m. Finally, in another 20 years, the distance between the baseline and the 2031 coastline is predicted to be 540.034 m, a loss from 2011 of about 24.28 m. Coastal erosion in the study area is likely to increase in the future.

In addition to the physical change, the impact of social which focused on the potential need for settlement and safety zone for the residential also found. In the central and southern areas of the beach where the urban area was the most increasing, the coastline changed radically and this affected community or utilities within 50-100 m of the shoreline. It means the safety zone in the central and southern area was the area after 100 m from the shoreline. In contrast, in the northern area of the beach there was less urban, the coastline changed less, and this affected community or utilities within 50 m of the shoreline. It means the safety zone in the northern area is the area after 50 m from the shoreline. The results of relationship analysis between land use and erosion and accretion showed a decrease in the aquaculture and agriculture area, turning them into bare land and urban area, especially resort. This is reflects the changes of livelihood and traditional lifestyle, such as from an agricultural society to accomodate much more about tourism. Also the economic loss has affected both the beach owner and the government to spend more budgets to protect the beach in various measures, both effective and ineffective. This economic impact analysis focuses on the analysis of damage on property values (buildings and infrastructure), land and social service on threatened beach. The calculation of economic vulnerability for the past 15 years on this study area was about 182.8.6 million baht, mainly in the middle and south of the study area.

2. The factors affecting coastal zone change in Hat Chao Samran

Analysis of coastal zone change for the past 15 years found that both natural and man-made factors were influenced. Because Hat Chao Samran is a long, straight beach, it is directly influenced by monsoons. Thus, monsoon weather and associated storms are very important influences on coastal zone changes in this area. At the same time, economic and social development plan of the Hat Chao Samran Municipal District caused markedly in the changing of land use along the coast, although this development plan improved the quality of life of the residents in Hat Chao Samran.

Natural factors

The relationships between natural factor and erosion and accretion were dominated by changes in monsoon weather, particularly during the second inter-monsoon and NE monsoon. The highest waves were found during the NE monsoon (0.1–3 m), followed by the second inter-monsoon (0.1–2.0 m), SW monsoon (0.1–1.7 m), and first inter-monsoon (0.1–1.3 m). The maximum current speed was observed during the second inter-monsoon (56.3–100.0 cm/s), followed by the NE monsoon (77.0–77.9 cm/s), first inter-monsoon (29.8–63.8 cm /s), and SW monsoon (10.4–39.1 cm/s). Another natural factor that is very important for erosion is extreme weather. There were 18 storms in October and 12 storms in November that moved into the Gulf of Thailand and passed near Petchaburi and Prachuapkhirikhan Provinces.

Man-made factors

The relationships between land use type and erosion and accretion was also computed using OLS and GWR technique. This indicates that the types of land use that influenced erosion in descending order were urban, aquaculture, bare land, mangroves, and agriculture. Also, the types of land use that influenced accretion in descending order were urban, aquaculture, mangroves, bare land, and agriculture. The spatial autocorrelation of land use types and erosion and accretion area expressed as erosion regression model (Erosion = -19.8929- $0.0025X_1+0.6643X_2+0.6261X_3+0.6622X_4+0.9221X_5$, $R^2 = 0.49$) and accretion regression model (Accretion=$-1.5946+0.1379X_1+0.1657X_2+0.0677X_3+0.0368X_4-0.1822X_5$, $R^2 = 0.07$). The value of R^2 indicated that erosion model quite fits independent variable or land use types. In contrast, accretion model does not relate to independent variable or land use types. This is due to the coefficient of the independent variables (land use types) are very low and small p-values, it do not help predict or relate to the accretion area. The breakwater and circulation pattern along the coast had more influent to accretion in the area than land use types.

The relationships between breakwater and erosion and accretion presented characteristics of anthropogenic factors that had the greatest influence on the coastal area at Hat Chao Samran is breakwaters which placed along the beach. The structure of the breakwater affected sediment movement along the coast. Benefits of breakwater is to reduce the strength of wind and wave, that attack the beach and reduce beach erosion but it is inevitable that it caused the changing of the beach shape from a straight beach to a dented beach. Additionally, with the geometry of the Hat Chao Samran the beach has been influenced by the monsoon variability and intensity of storms will affect the longshore current, especially NE monsoon and 2nd transition period. This barrier effected the movement of sediment and caused the balance of sediment in the area. The critical area was protected, but it affected beach changing in the north and south of the structure. Thus, the use of hard structure to be protection measure in long-term should be carefully considered in order to achieve real sustainable solutions.

Generally, factors affecting the erosion and accretion in the study area can be clearly divided into three periods:

1. Before breakwater construction (1999–2006), the changes in the coastal area during this period are consistent with natural factors such as wind, waves, current and associated also with the monsoon periods, especially in the end of the NE monsoon to the middle of the first inter-monsoon. The land use that influenced erosion in descending order was urban, aquaculture, bare land, mangroves, and agriculture.

2. During breakwater construction (2007–2008), analysis of historical data showed that the monsoon season that induced tropical storm was still a factor influencing this area. The current flows from south to north during the first inter-monsoon, causing erosion in the southern area and sediment deposition mainly in the northern area. There was also slight erosion and more accretion associated with construction of the breakwater in the area.

3. After breakwater construction (2009–2011), erosion and accretion were still problem. The natural factors in normal and extreme weather influenced the area. There were tropical storms that moved into the Gulf of Thailand and passed near Petchaburi and Prachuapkhirikhan Provinces in 2007, 2010 and 2011 (Fig 27a). The breakwater had markedly an influence in the central area, resulted in accumulation of sediment in that area. Land use, especially increasing in bare land and urban also influenced.

3. Sustainable management for coastal zone change at Hat Chao Samran

Sustainable management for coastal zone change need balancing of environment, social and economic and should be concerned taking a long-term view in order to enhance an understanding of specific area. With the physical characteristics of the coastal zone is dynamics, therefore long-term continuous data is very important in management. In the case of Hat Chao Samran, which coastal area changes depended on both the influence of natural factors and human activities. From the analysis of the physical changes as Table 11 shows that under influence of natural factor, the changing of coastal area was about 6 years for critical erosion and accretion as during 2005-2006. But when the influence of anthropogenic factor involved in a critical erosion and accretion area, it was only about 4 years as during 2009-2010. So if there is the limit on the long-term continuous data, researchers can use the information in the last 6 years, which can also see the changes of the coastal area situation. The sustainable management of coastal areas needs to focus on the factors that are relevant and sensitive in areas in many dimensions. For Hat Chao Samran, the sensitivity index in this study based on Geo-indicators consisting of monsoon, wave, wind, current, land use, erosion area and erosion-accretion rate. By weighting these sensitivity indexes during1999-2011and mapping into the risk area, the results showed that the indexes influenced changes in the critical level, including NE monsoon, wind speed> 20 m/s, wave height> 2 m, Current speed> 60 cm/s, land use (mangrove, aquaculture) and. erosion rate> 5 m/yr. It can be seen that the risk map base on geo-indicators expressed that the most areas of Hat Chao Samran had medium vulnerability (erosion 1-5 m/yr.), except the central, southern and some part of the north area, which was high vulnerable (erosion >5 m/yr.) to coastal changes.

Due to sustainable management planning and measurement to solve the coastal erosion problem is important to integrate the involved factor of the eroded area in physical, social and economic. Then analyzing the risk area due to changes in coastal areas with the long-term spatial modeling, which combined the physical and socioeconomic risks provided the risk area in more details consisting severe erosion area, the risk of settlement areas and affected area to economic losses were very essential. For this study long-term spatial modeling base on Model/Builder of ArcGIS software was introduced. In case of Hat Chao Samran, risk area analyzed by long-term spatial modeling provided the high risk areas in the middle, some areas of the south, especially estuaries and some in the north at a distance of 0-50 meters from the shoreline. Medium risk area was along the coast at a distance of 50-100 meters from the shoreline, and the low risk areas were over 100 meters onwards. This risk map was not only providing the risk area but also giving the information of safety zone along the coast. It can be seen that the risk map base on long-term spatial modeling to provide details on every dimension, including physical, social and economic aspect. The study of coastal zone change by using long-term spatial modeling as a tool will provide an overview of the changes in the area in the long term. Therefore, considering measures to tackle coastal erosion in the area can be considered the cause, effect on all sides, as well as future changes that will occur in the area. The long-term spatial model of Hat Chao Samran can be applied to other areas that look like Hat Chao Samran by adjusting the input of each area.

Recommendations

1. Analysis and monitoring the status of coastal erosion in any area should take into consideration the long-term data set because of coastal area is dynamic over time. Therefore, the use of short-term information may cause misunderstanding, establishment wrong solution and enhance the impact on the adjacent area.

2. Due to the use of statistical techniques and spatial analysis together for science research, it is still not widely used. A major problem with the statistical techniques when applied to spatial data is that the processes being examined are assumed to be constant over space – that is, one model fits all. In the case of coastal areas are dynamic, spatial modeling should be adjusted and add more type and amount of independent variable in order to increase the accuracy of the model. In the spatial application, one spatial model fits for one coastal area. For this study, spatial modeling which is used for Hat Chao Samran but in order to apply for other similar areas, the appropriate variables for certain area should be adjusted such as long-term physical impact in term of erosion and accretion rate, social impact including long-term shorelines change and urban area and economic impact consists of erosion and accretion area, location of building and structure and the social service of the beach.

3. The long-term spatial modelling approach using ModelBuilder employed in this study can be developed into an automated process with various programming languages for routine use. This geo-processing linear feature model can be used to repeat development of similar binary and ranking models. Once the steps are visually diagrammed and run, the model as a whole can be saved and shared among multiple users. This long-term automated geo-processing tool provides a useful application and easy adjustment for other beaches in Thailand to improve monitoring, analysis, and prediction systems for coastal zone management.

4. In the case of Hat Chao Samran, if there is the limit on the long-term continuous data, researchers can use the information in the last 6 years, which can also see the changes of the coastal area situation.

5. The management for coastal erosion problem should focus on the basic characteristics of the beach or beach system, the factors involved in each beach, risk areas analysis covered in all dimension, the use of long-term continuous data, not certain period of time, to consider the establishment of a central spatial database for coastal areas in order to reduce duplication of the budget and to improve the accuracy of the overview coastal situation. Also relevant agencies should pay more attention both in the critical area and adjacent area, including integrated together in all sectors related to coastal zone management in order to achieve the sustainability of coastal zone.

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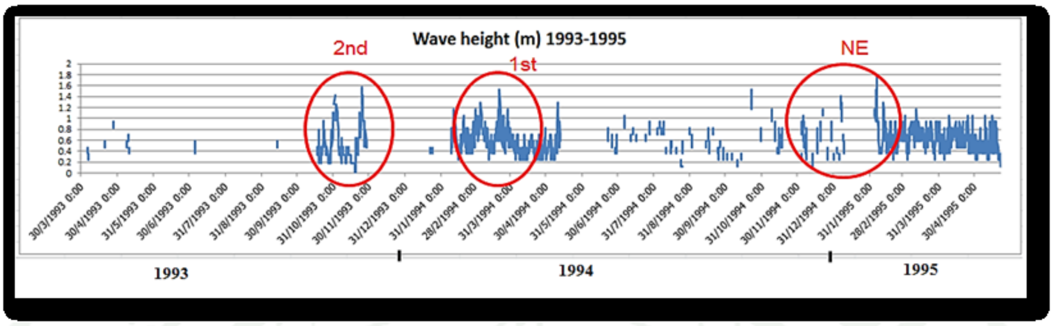
APPENDICES

APPENDIX A

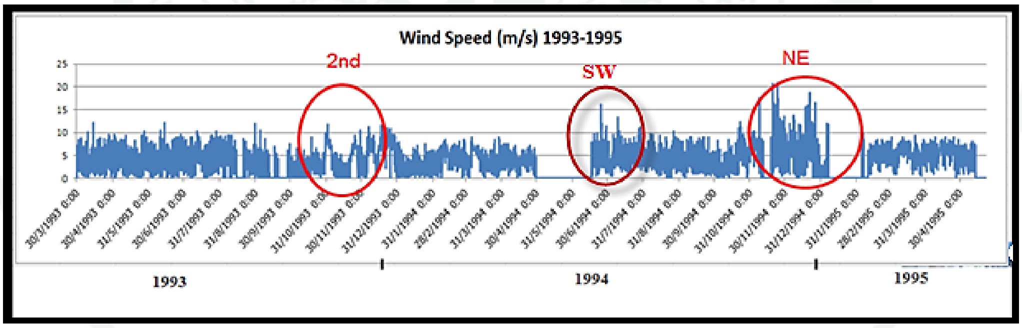
Historical Natural Factors (1993-2006)

Historical Natural Factors (1993-2006)

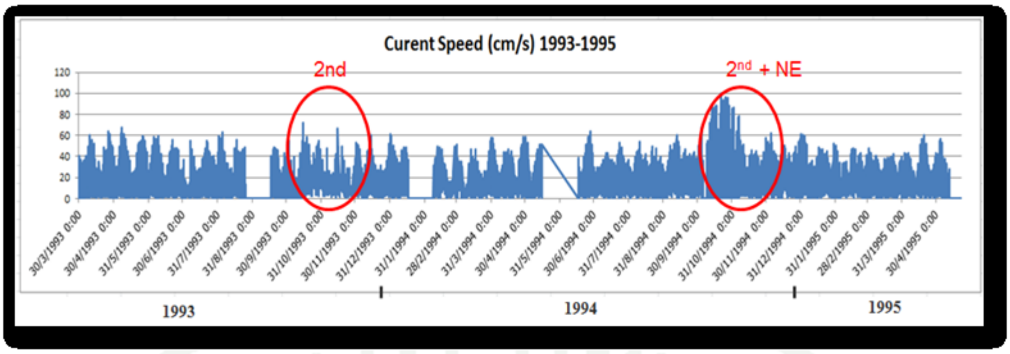
Wind-wave-current 1993-1995



Appendix Figure 1 Time series of wave height during 1993-1995. Maximum wave in the 1993, 1994 and 1995 recorded in the 2nd inter-monsoon, 1st inter-monsoon and NE. monsoon respectively with maximum wave height 1.6-1.8 m.

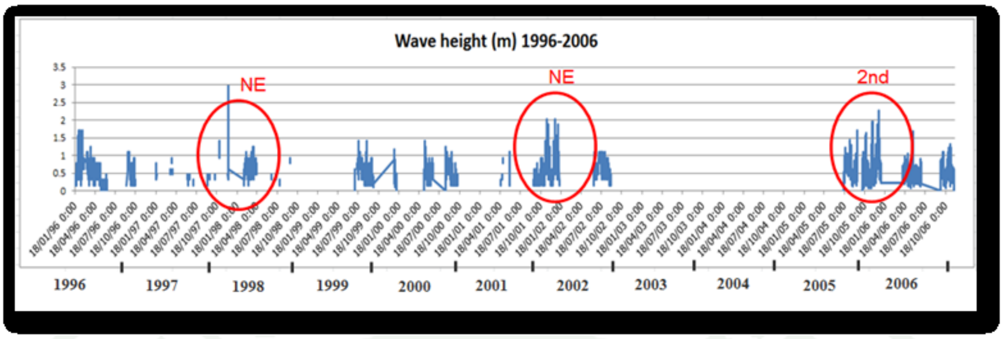


Appendix Figure 2 Time series of wind speed during 1993-1995. Maximum wind speed in the 1993, 1994 and 1995 recorded in the 2nd inter-monsoon, SW monsoon and NE. monsoon respectively with maximum wind speed 15-25 m/s.

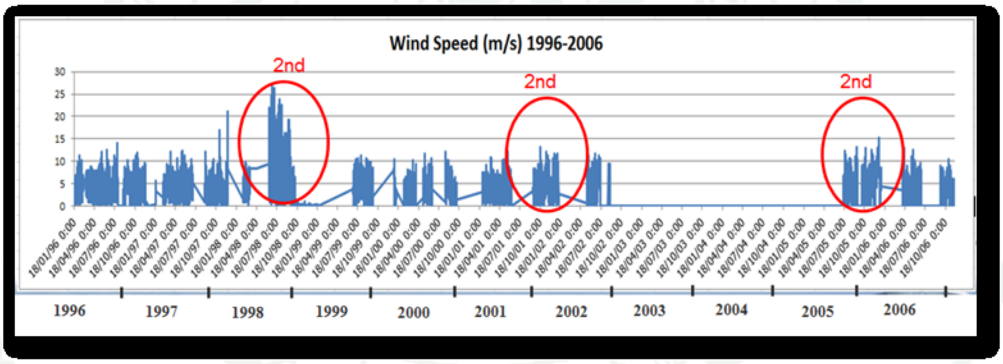


Appendix Figure 3 Time series of current speed during 1993-1995. Maximum current speed in the 1993 and 1994 were in the 2nd inter-monsoon and 2nd inter-monsoon & NE. monsoon respectively with maximum current speed 70-100 cm/s. As opposed to 1995, it relatively unchanged.

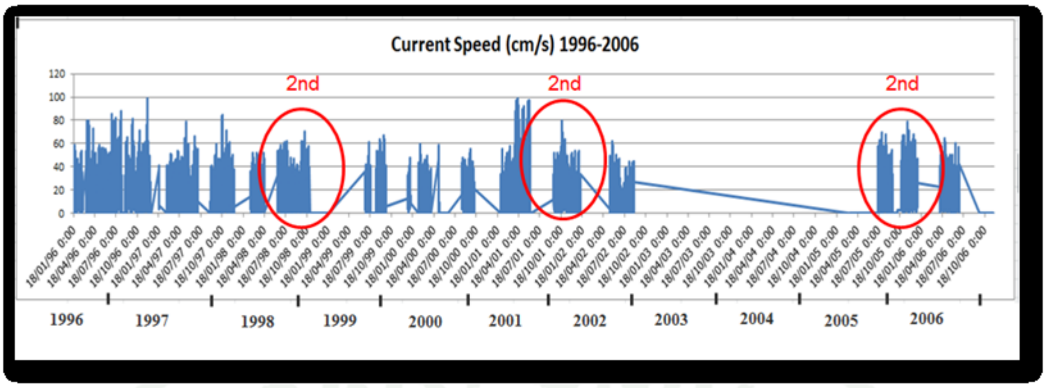
Wind-wave-current 1996-2006



Appendix Figure 4 Time series of wave height during 1996-2006. Maximum wave height during 1996-2006 presented in the NE monsoon of 1998, NE monsoon of 2002 and 2nd inter-monsoon of 2006 with maximum wave height 2-2.3 m.



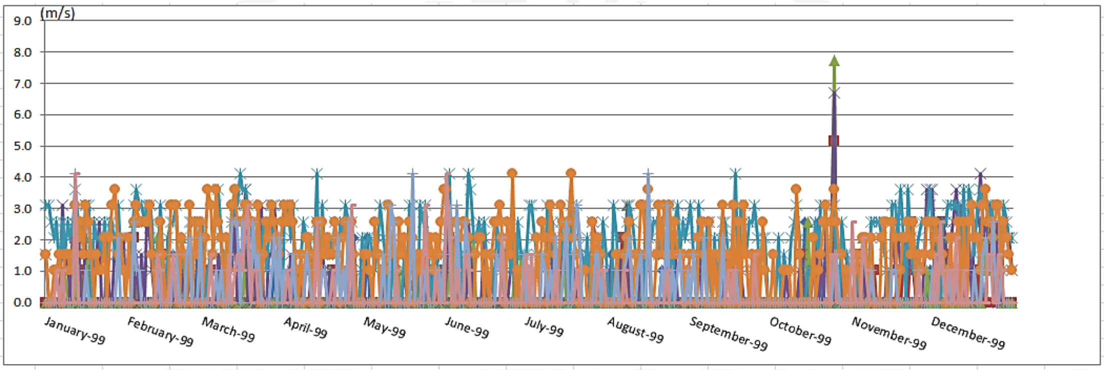
Appendix Figure 5 Time series of wind speed during 1996-2006. Maximum wind speed during 1996-2006 presented in the 2nd inter- monsoon of 1998, 2nd inter- monsoon of 2002 and 2nd inter-monsoon of 2006 with maximum wind speed 15-25 m/s.



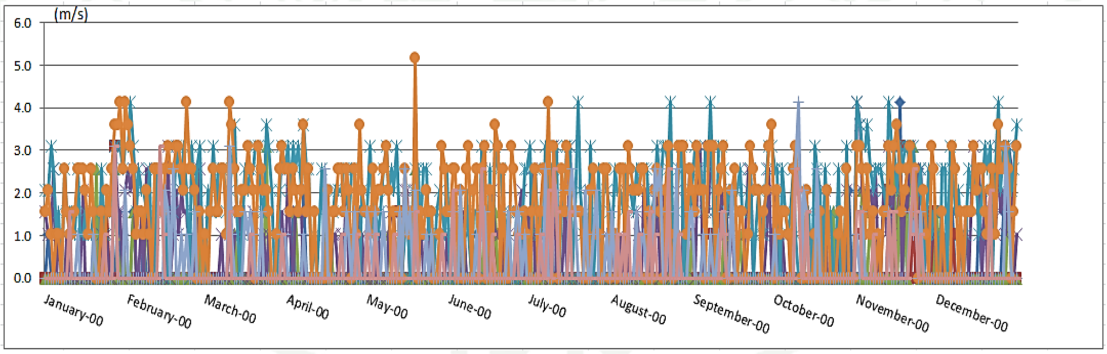
Appendix Figure 6 Time series of current speed during 1996-2006. Maximum current speed during 1996-2006 presented in the 2nd inter-monsoon of 1998, 2nd inter- monsoon of 2002 and 2nd inter-monsoon of 2006 with maximum current speed 70-100 cm/s.

Wind in 1999-2011

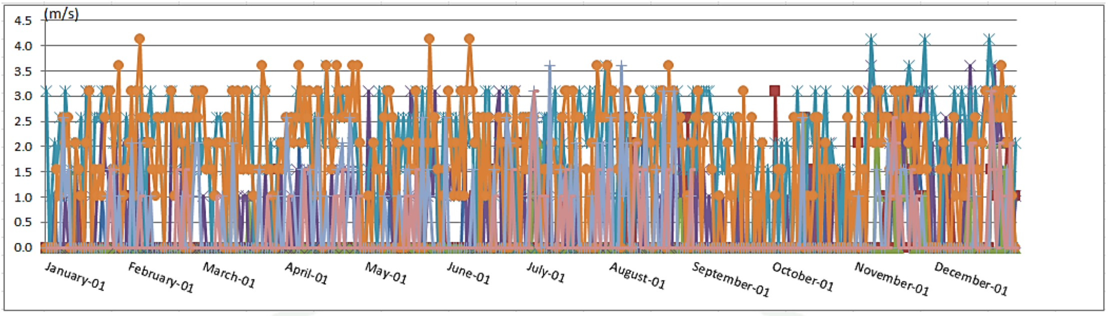
Considering of wind climate from Thai Meteorological Department during 1999-2011, mostly the magnitude of wind speed was stronger in NE monsoon (Nov-Jan) than the other season. The data are as shown in figure 7.



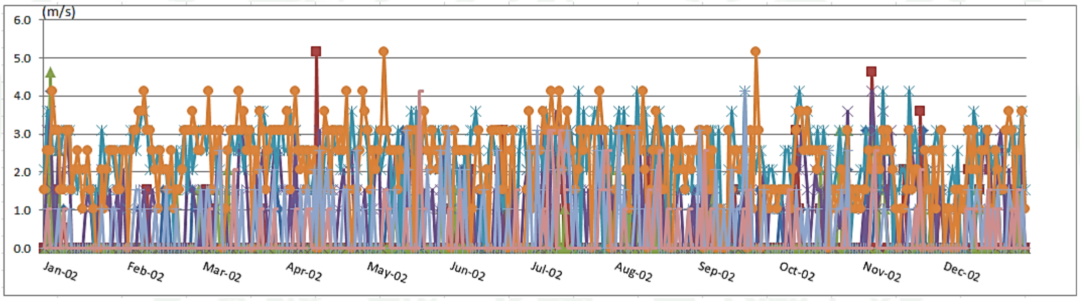
Appendix Figure 7 Wind climate in 1999 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 8 m/s.



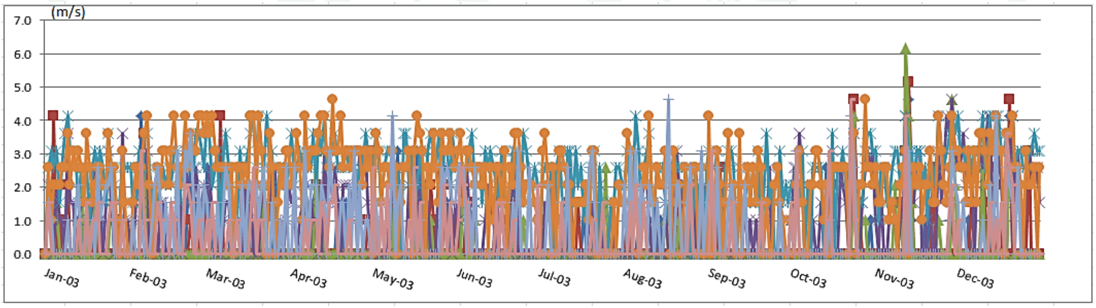
Appendix Figure 8 Wind climate in 2000 recorded that it was a strong magnitude in SW monsoon (May-Aug). The maximum wind speed was 5 m/s.



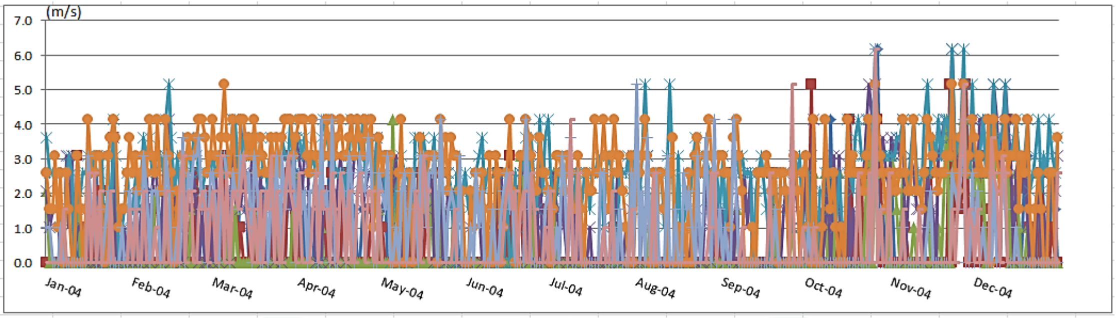
Appendix Figure 9 Wind climate in 2001 recorded that it was a strong magnitude in SW monsoon (May-Aug) and NE monsoon (Nov-Jan) . The maximum wind speed was 4 m/s.



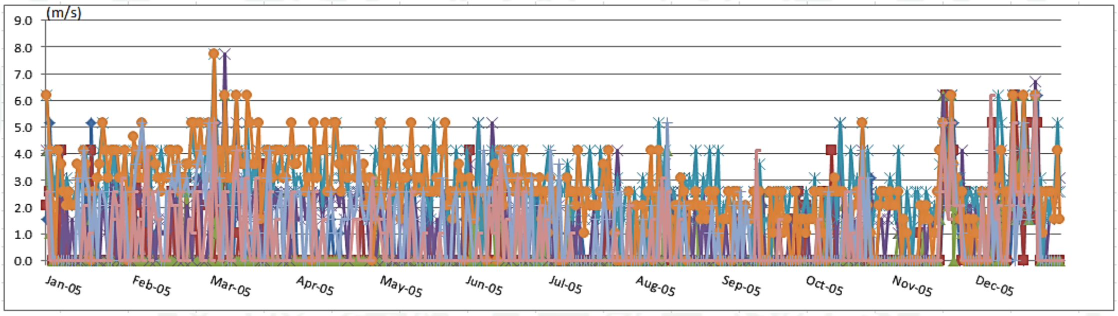
Appendix Figure 10 Wind climate in 2002 recorded that it was a strong magnitude in SW monsoon (May-Aug) and 2nd transition period (Sep-Oct) . The maximum wind speed was 5 m/s.



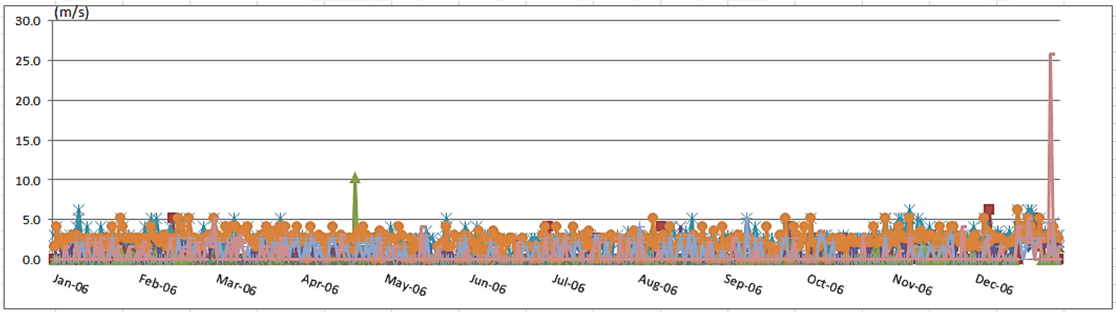
Appendix Figure 11 Wind climate in 2003 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 6 m/s.



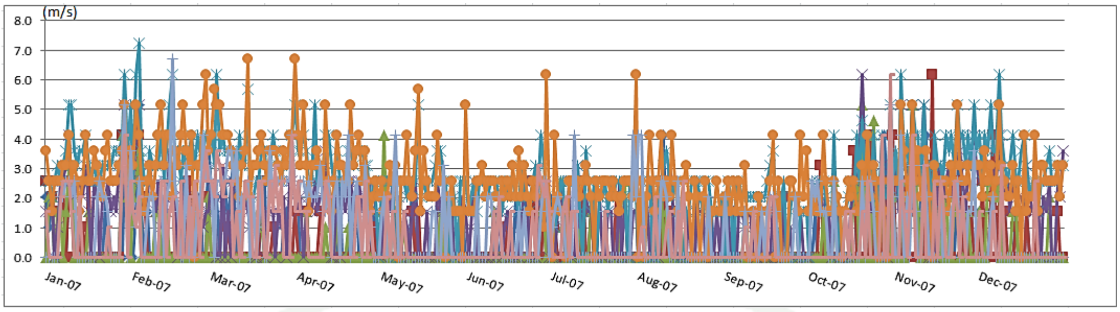
Appendix Figure 12 Wind climate in 2004 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 6 m/s.



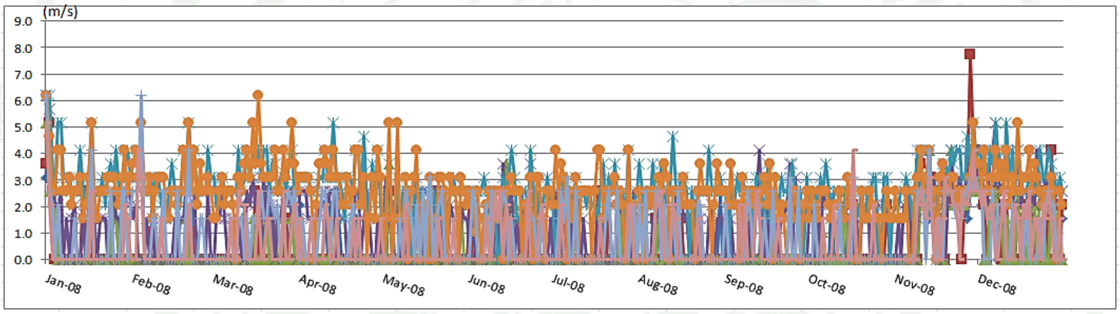
Appendix Figure 13 Wind climate in 2005 recorded that it was a strong magnitude in 1st transition period (Feb-Apr). The maximum wind speed was 8 m/s.



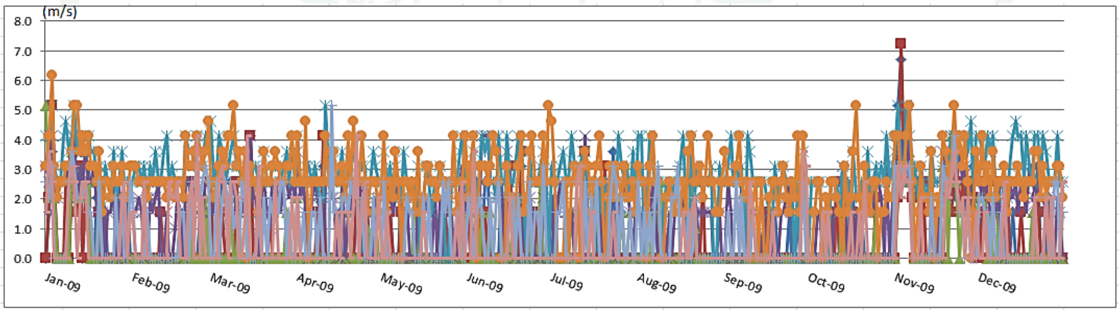
Appendix Figure 14 Wind climate in 2006 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 25 m/s.



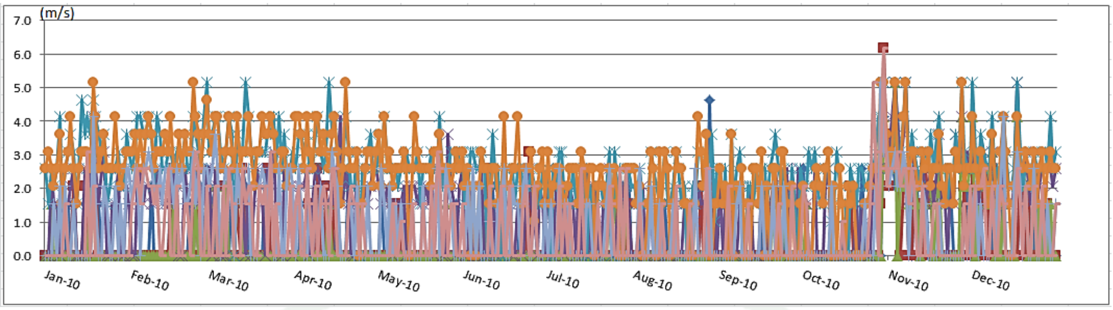
Appendix Figure 15 Wind climate in 2007 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 7 m/s.



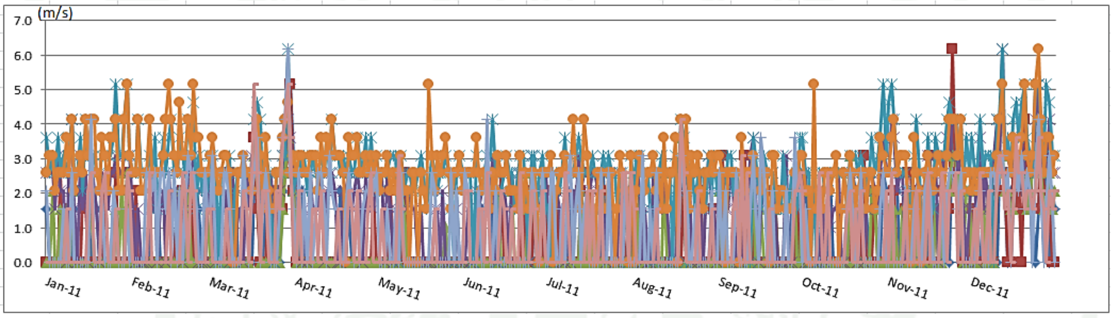
Appendix Figure 16 Wind climate in 2008 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 8 m/s.



Appendix Figure 17 Wind climate in 2009 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 7 m/s.



Appendix Figure 18 Wind climate in 2010 recorded that it was a strong magnitude in NE monsoon (Nov-Jan). The maximum wind speed was 6 m/s.



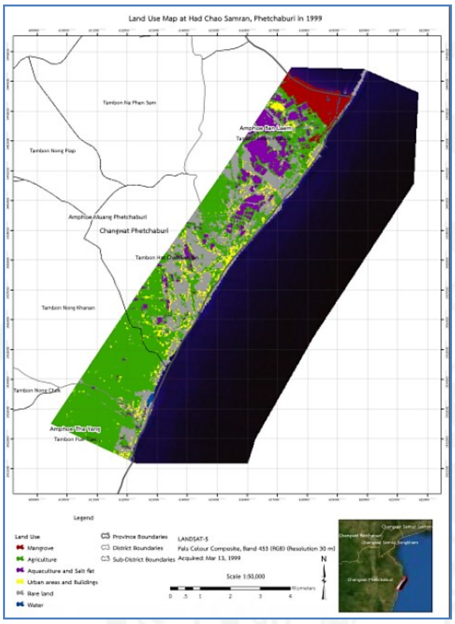
Appendix Figure 19 Wind climate in 2011 recorded that it was a strong magnitude in NE monsoon (Nov-Jan) and 1st transition period (Feb-Apr). The maximum wind speed was 6 m/s.

APPENDIX B

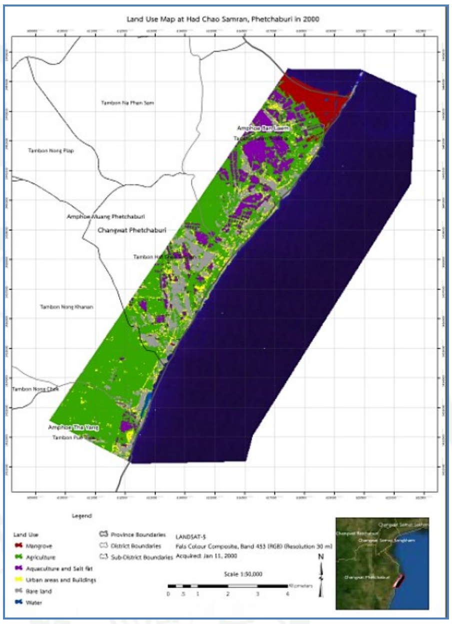
Historical Anthropogenic Factors (1999-2011)

Historical Anthropogenic Factors

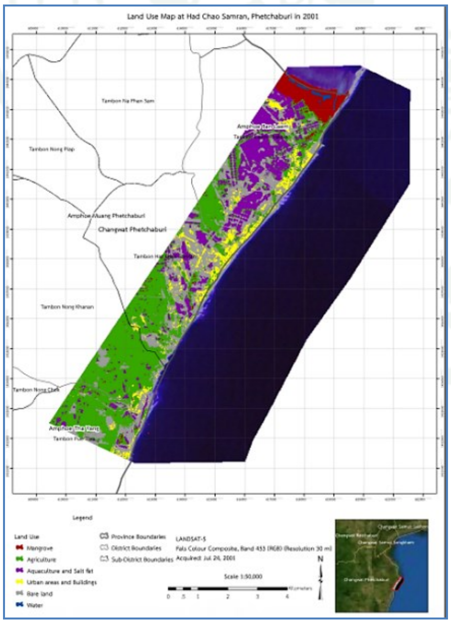
Land use change during 1999-2011 at Hat Chao Samran



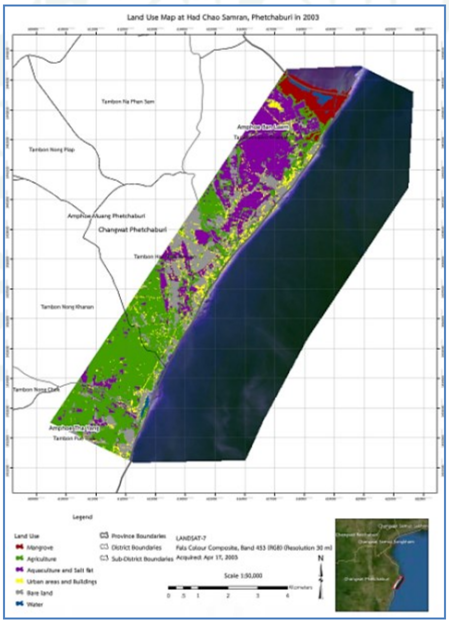
Appendix Figure 20 Land use map in 1999



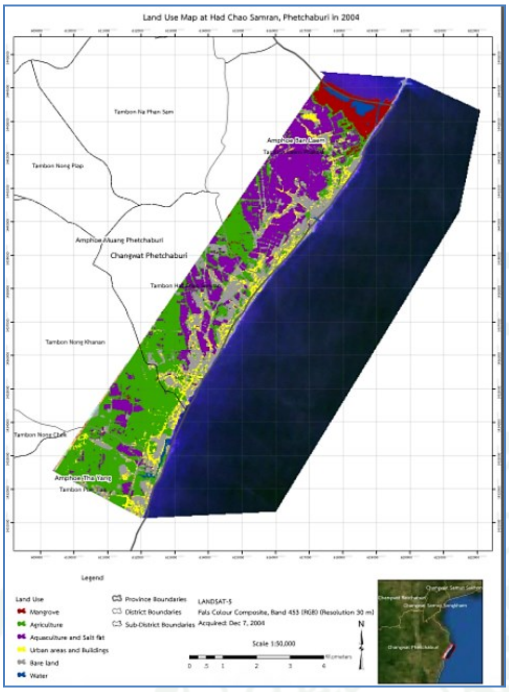
Appendix Figure 21 Land use map in 2000



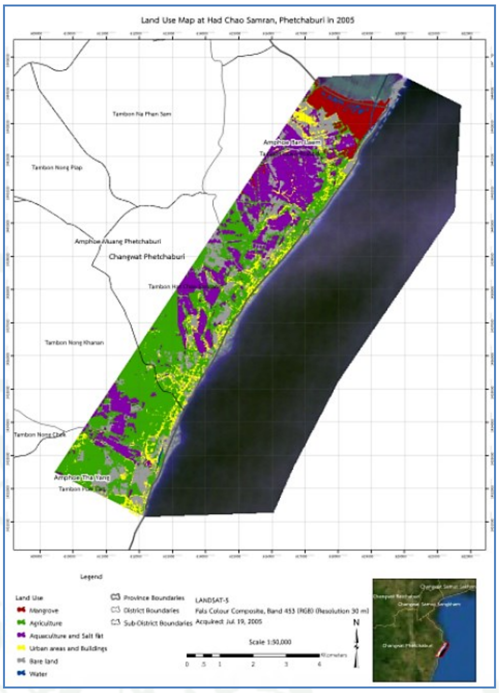
Appendix Figure 22 Land use map in 2001



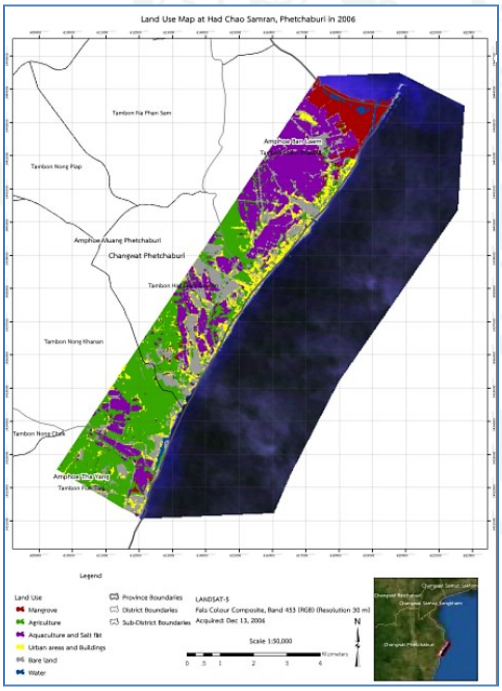
Appendix Figure 23 Land use map in 2003



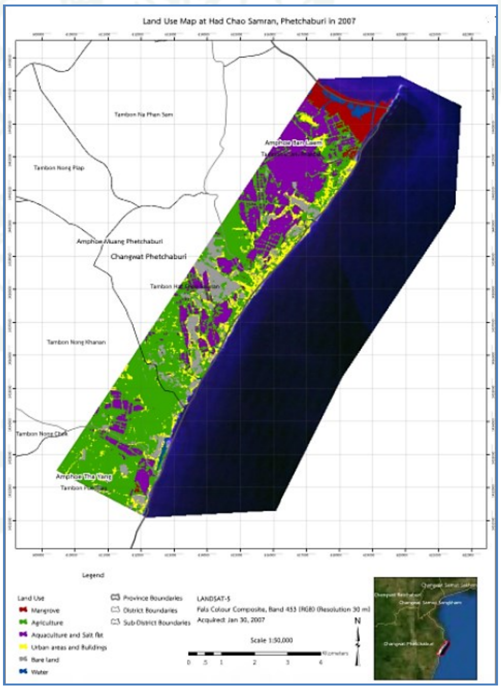
Appendix Figure 24 Land use map in 2004



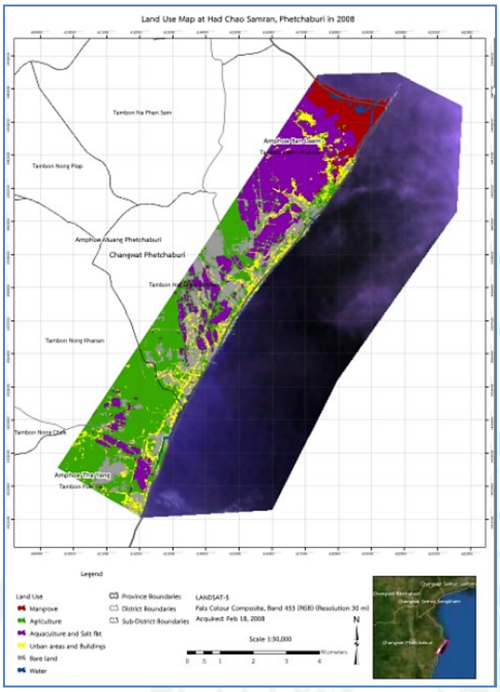
Appendix Figure 25 Land use map in 2005



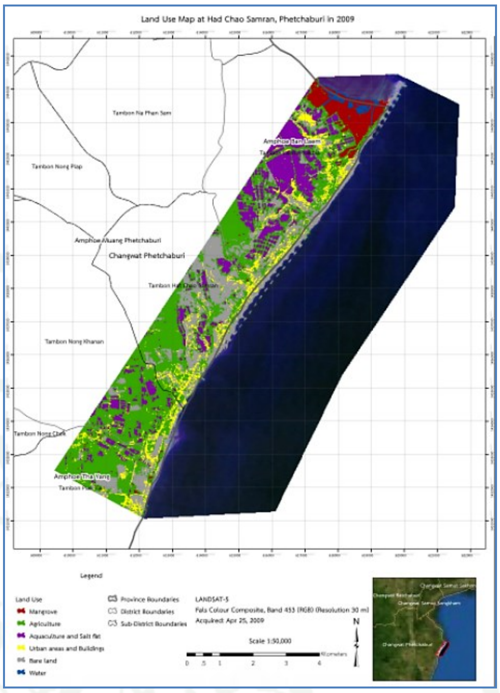
Appendix Figure 26 Land use map in 2006



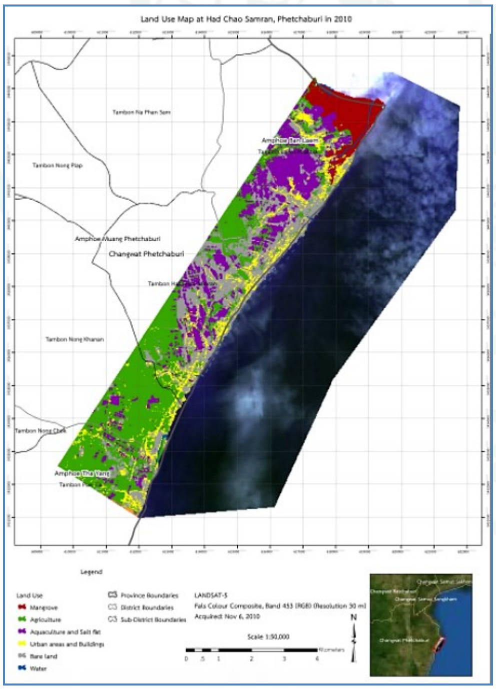
Appendix Figure 27 Land use map in 2007



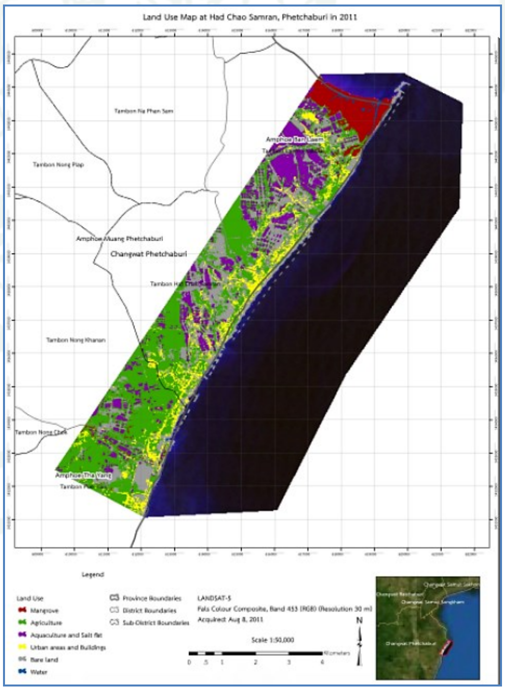
Appendix Figure 28 Land use map in 2008



Appendix Figure 29 Land use map in 2009



Appendix Figure 30 Land use map in 2010



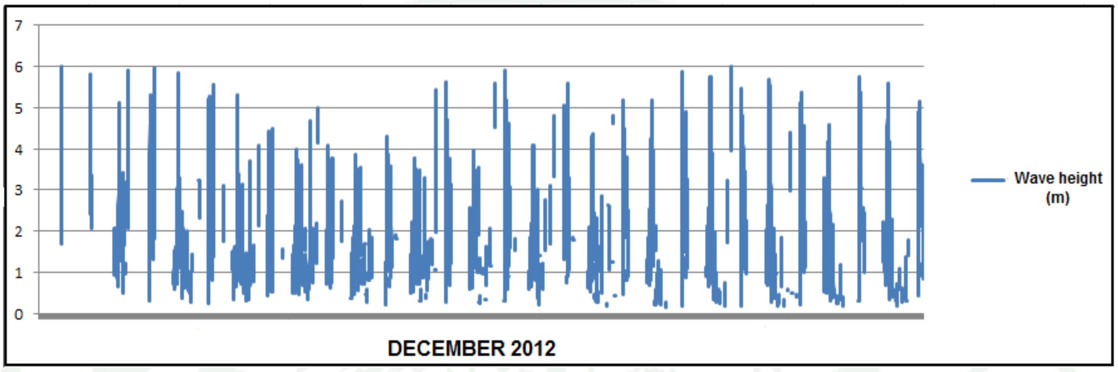
Appendix Figure 31 Land use map in 2011

APPENDIX C

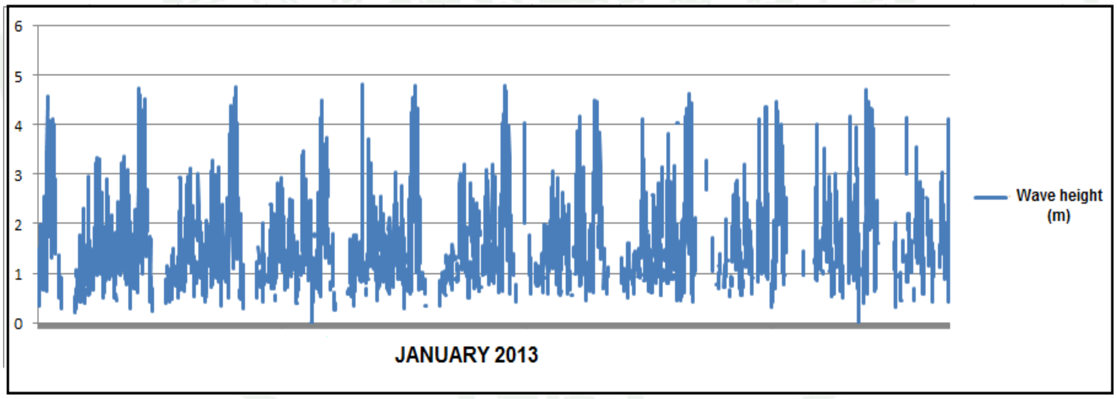
Present Natural Factors (2012-2013)

Present Natural Factors (2012-2013)

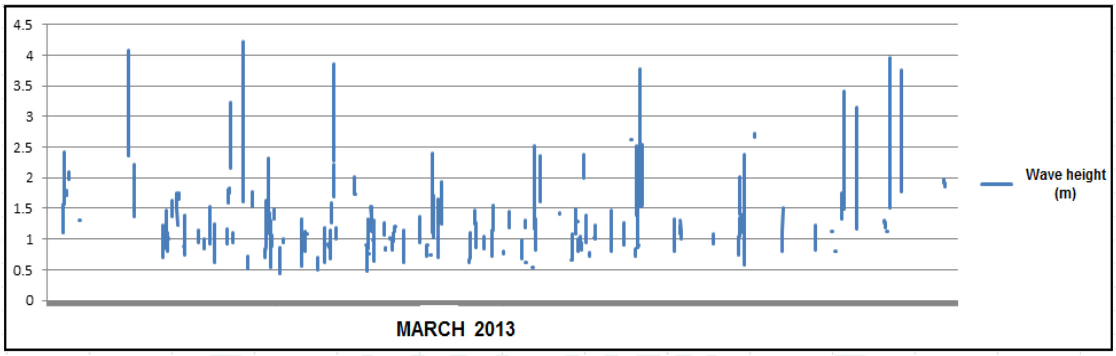
Wave characteristic from Coastal Radar System of GISTDA between 2012 and 2013



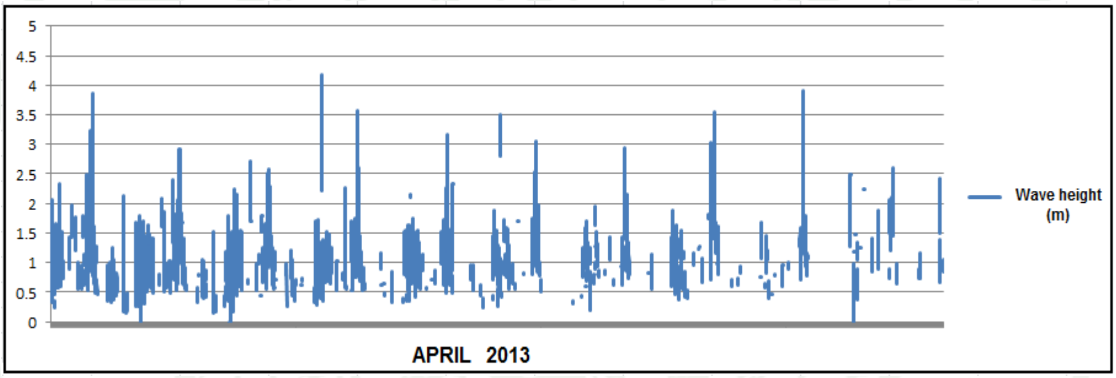
Appendix Figure 32 Time series of wave height in December 2012. Maximum wave height was 4.96 m, minimum was 0.15 m and average wave height was 1.75 m.



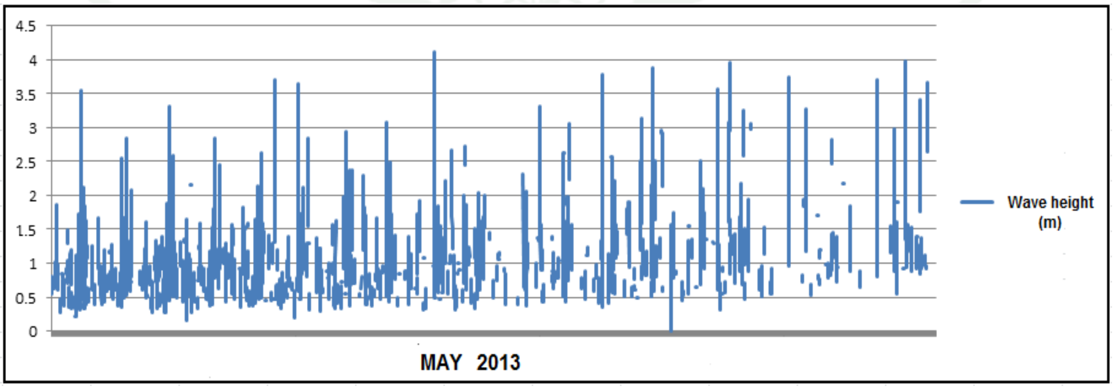
Appendix Figure 33 Time series of wave height in January 2013. Maximum wave height was 4.81 m, minimum was 0.2 m and average wave height was 1.56 m.



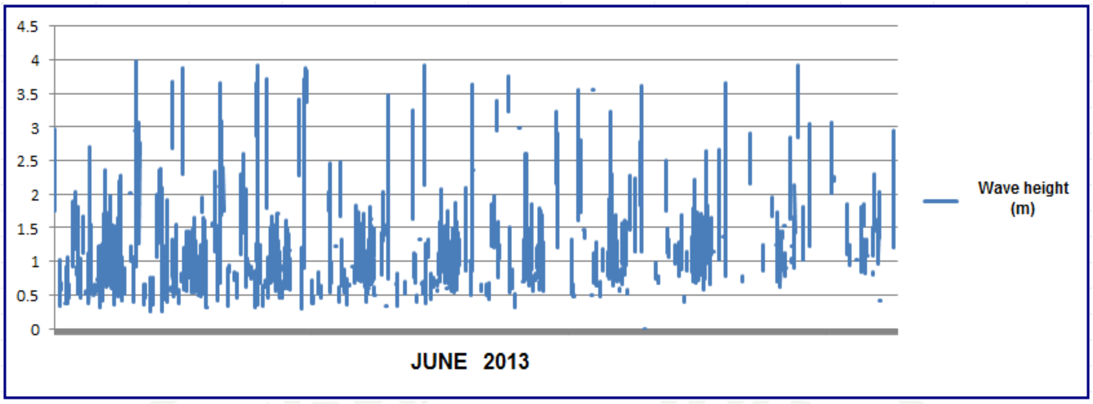
Appendix Figure 34 Time series of wave height in March 2013. Maximum wave height was 4.23 m, minimum was 0.38 m and average wave height was 1.31 m.



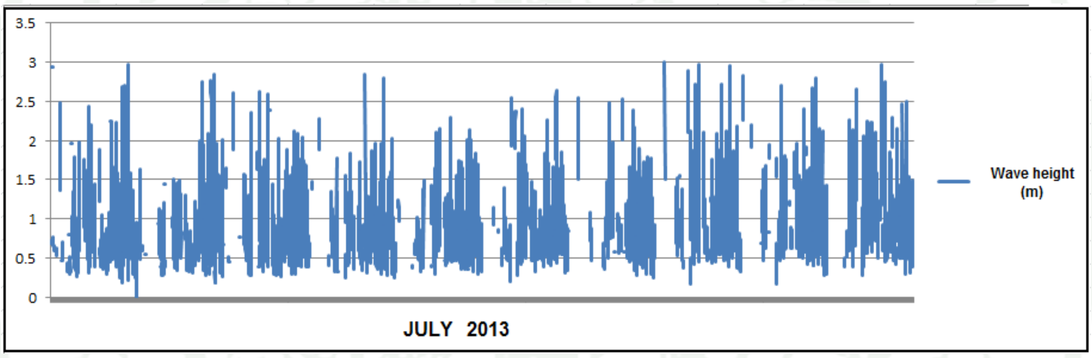
Appendix Figure 35 Time series of wave height in April 2013. Maximum wave height was 4.33 m, minimum was 0.15 m and average wave height was 1.09 m.



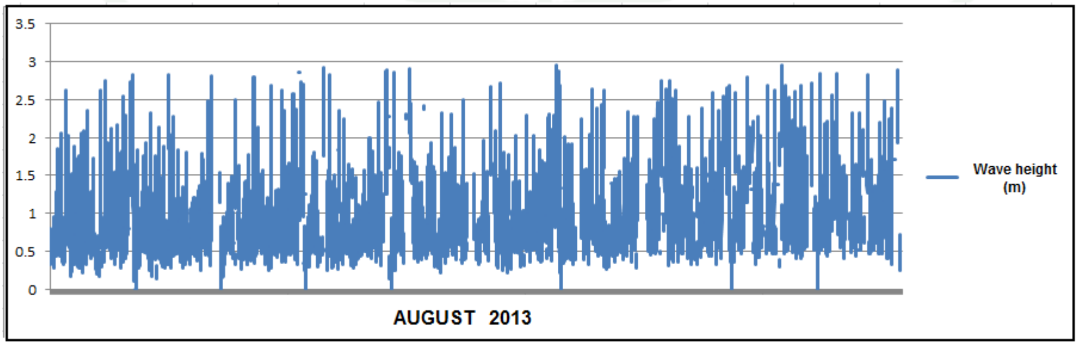
Appendix Figure 36 Time series of wave height in May 2013. Maximum wave height was 4.12 m, minimum was 0.16 m and average wave height was 1.02 m.



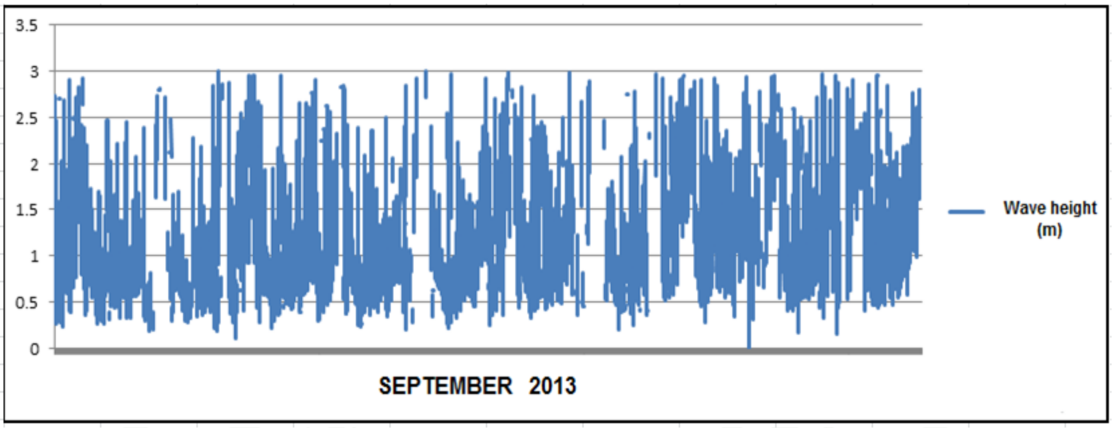
Appendix Figure 37 Time series of wave height in June 2013. Maximum wave height was 4.0 m, minimum was 0.25 m and average wave height was 1.14 m.



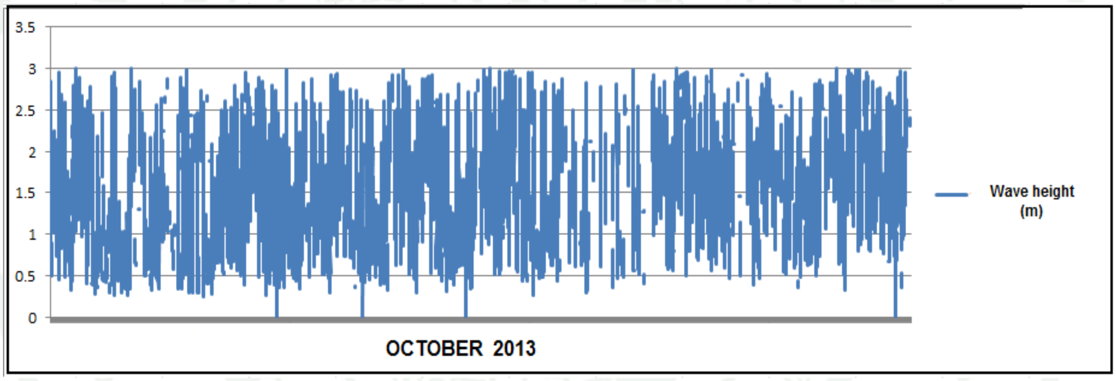
Appendix Figure 38 Time series of wave height in July 2013. Maximum wave height was 3.22 m, minimum was 0.1 m and average wave height was 0.88 m.



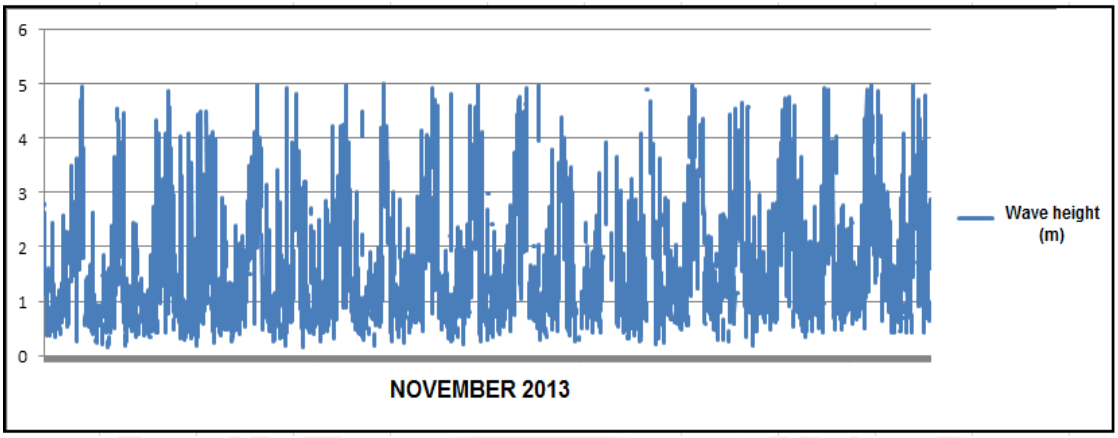
Appendix Figure 39 Time series of wave height in August 2013. Maximum wave height was 3.0 m, minimum was 0.1 m and average wave height was 0.86 m.



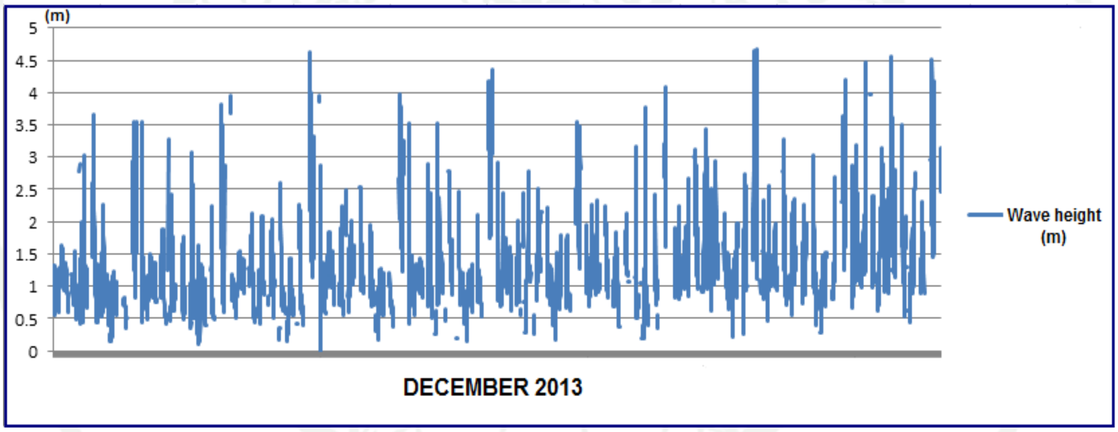
Appendix Figure 40 Time series of wave height in September 2013. Maximum wave height was 3.0 m, minimum was 0.11 m and average wave height was 1.07 m.



Appendix Figure 41 Time series of wave height in October 2013. Maximum wave height was 3.0 m, minimum was 0.1 m and average wave height was 1.36 m.

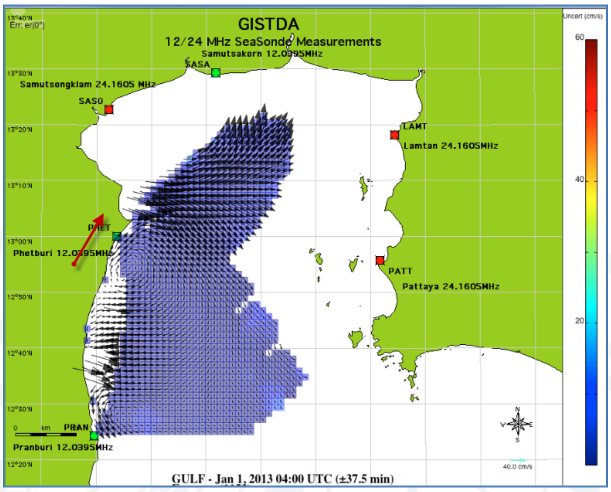


Appendix Figure 42 Time series of wave height in November 2013. Maximum wave height was 5.0 m, minimum was 0.16 m and average wave height was 1.39 m.

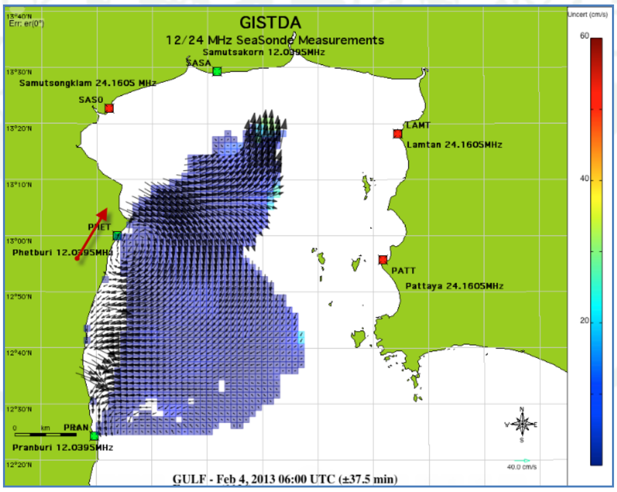


Appendix Figure 43 Time series of wave height in December 2013. Maximum wave height was 4.66 m, minimum was 0.1 m and average wave height was 1.3 m.

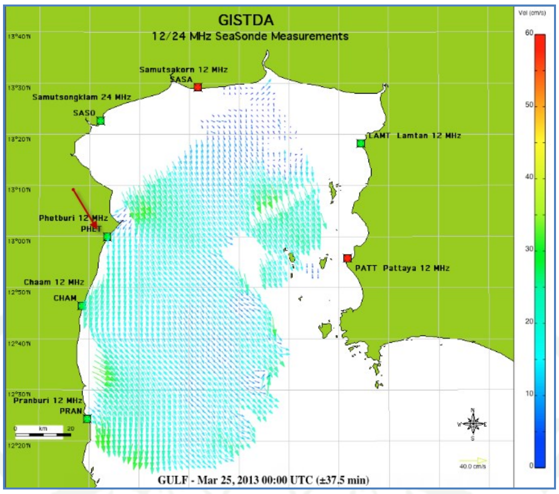
Current Pattern from Coastal Radar System of GISTDA between 2012 and 2013



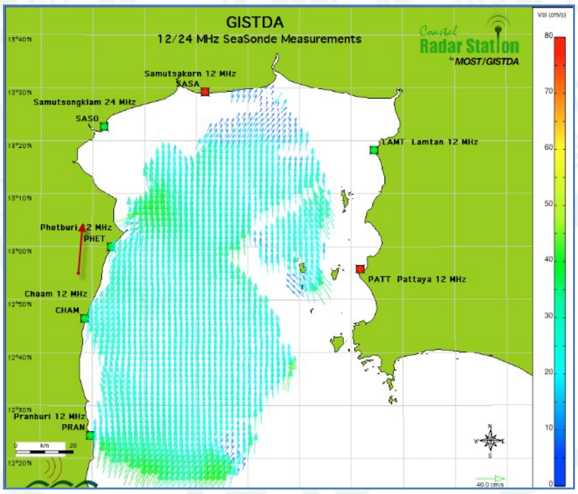
Appendix Figure 44 Circulation pattern at Hat Chao Samran in January 2013. Maximum wave height was 80 cm/sec, minimum was 0.01 cm/sec and average wave height was 17.74 cm/sec. The main direction was E and NE.



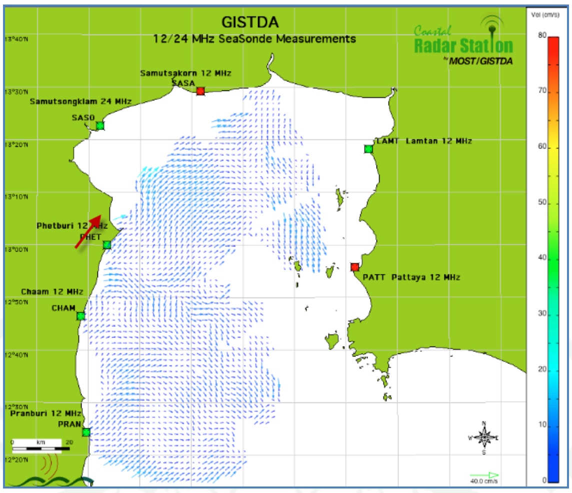
Appendix Figure 45 Circulation pattern at Hat Chao Samran in February 2013. Maximum wave height was 80 cm/sec, minimum was 0.06 cm/sec and average wave height was 15.36 cm/sec. The main direction was E and NE.



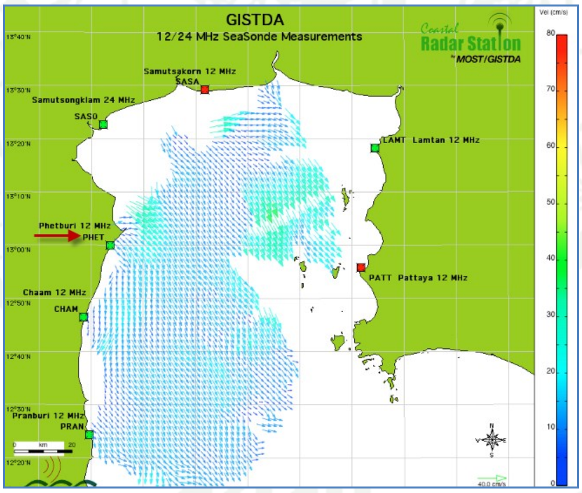
Appendix Figure 46 Circulation pattern at Hat Chao Samran in March 2013. Maximum wave height was 100 cm/sec, minimum was 0.002 cm/sec and average wave height was 19.85 cm/sec. The main direction was SE.



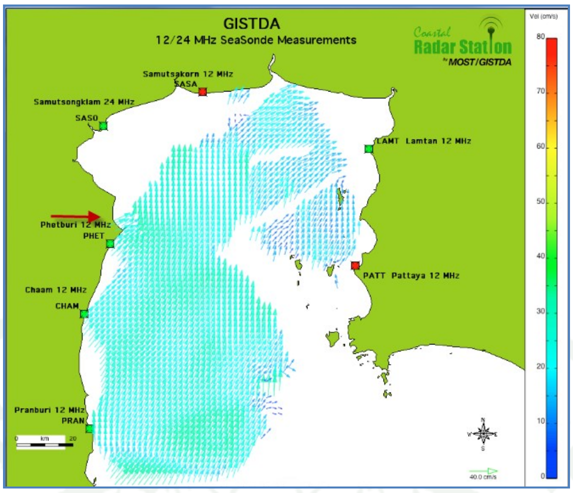
Appendix Figure 47 Circulation pattern at Hat Chao Samran in April 2013. Maximum wave height was 50.67 cm/sec, minimum was 0.005 cm/sec and average wave height was 9.56 cm/sec. The main direction was N.



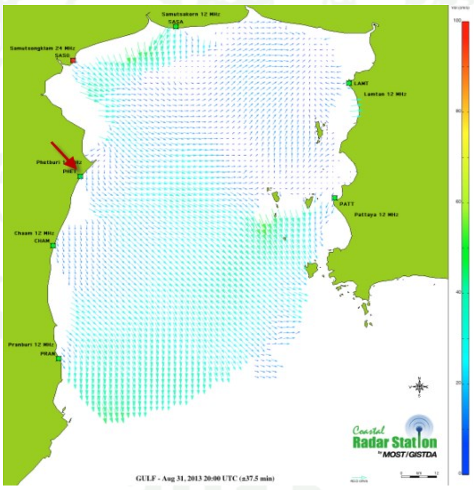
Appendix Figure 48 Circulation pattern at Hat Chao Samran in May 2013. Maximum wave height was 9.86 cm/sec, minimum was 0.08 cm/sec and average wave height was 2.84 cm/sec. The main direction was NE.



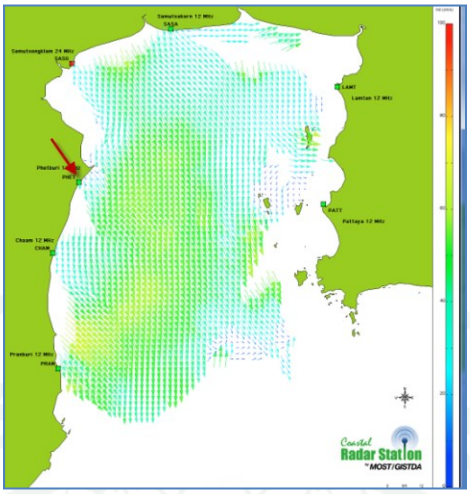
Appendix Figure 49 Circulation pattern at Hat Chao Samran in June 2013. Maximum wave height was 12.26 cm/sec, minimum was 0.69 cm/sec and average wave height was 5.74 cm/sec. The main direction was E.



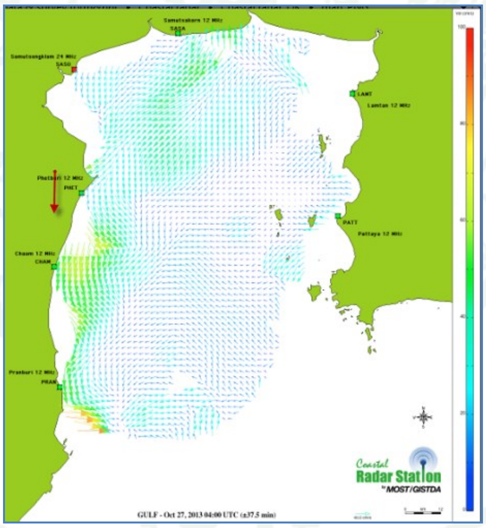
Appendix Figure 50 Circulation pattern at Hat Chao Samran in July 2013. Maximum wave height was 14.52 cm/sec, minimum was 0.57 cm/sec and average wave height was 6.67 cm/sec. The main direction was E.



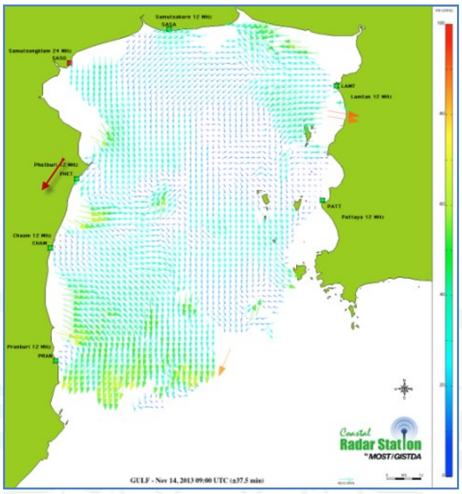
Appendix Figure 51 Circulation pattern at Hat Chao Samran in August 2013. Maximum wave height was 12.24 cm/sec, minimum was 0.16 cm/sec and average wave height was 6.57 cm/sec. The main direction was SE.



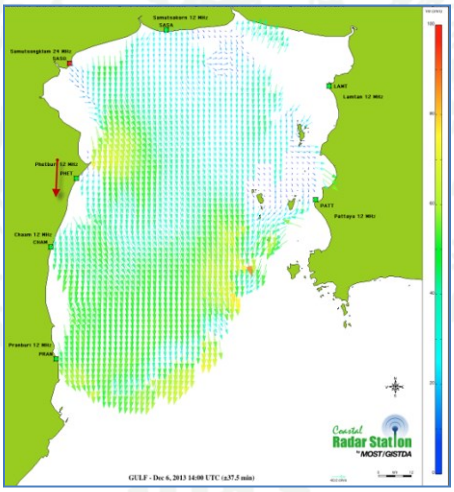
Appendix Figure 52 Circulation pattern at Hat Chao Samran in September 2013. Maximum wave height was 17.89 cm/sec, minimum was 9.33 cm/sec and average wave height was 0.31 cm/sec. The main direction was SE.



Appendix Figure 53 Circulation pattern at Hat Chao Samran in October 2013. Maximum wave height was 22.94 cm/sec, minimum was 0.73 cm/sec and average wave height was 12.45 cm/sec. The main direction was S.



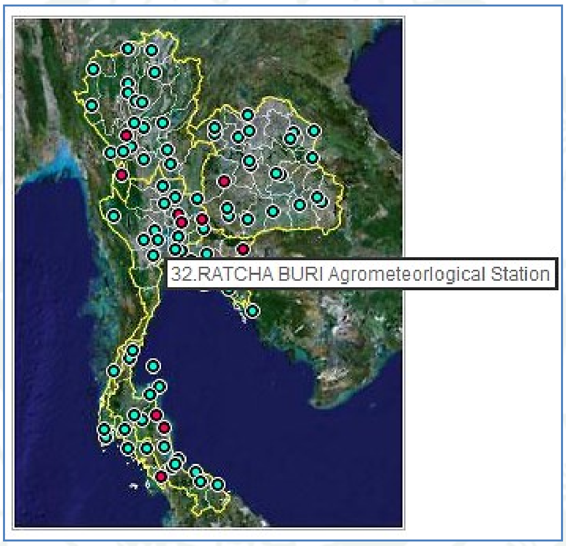
Appendix Figure 54 Circulation pattern at Hat Chao Samran in November 2013. Maximum wave height was 32.82 cm/sec, minimum was 12.03 cm/sec and average wave height was 0.75 cm/sec. The main direction was SW.



Appendix Figure 55 Circulation pattern at Hat Chao Samran in December 2013. Maximum wave height was 58.55 cm/sec, minimum was 0.86 cm/sec and average wave height was 15.78 cm/sec. The main direction was S.

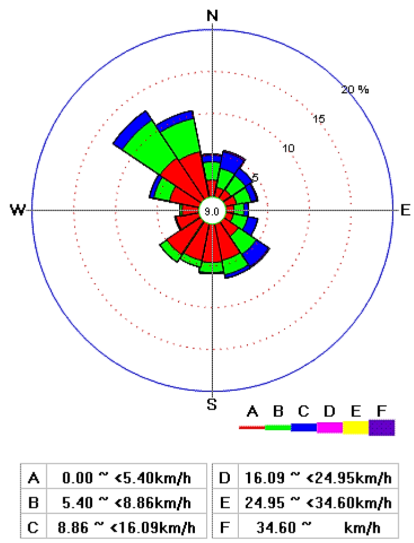
Wind Climate From Ratchaburi Agrometeorlogical Station

The wind climate from January to December 2013 except October was obtained from Ratchaburi Agrometeorlogical station where it is closed to Chao Samran beach. The weather condition was periodically dominated by the high pressure area from China covering upper Thailand (NE monsoon), the South China Sea and the Andaman sea (SW monsoon), the combination of the prevailing of the northeast monsoon across southern part and the Gulf of Thailand and the southeasterly wind blowing over the central and eastern parts.



Appendix Figure 56 Wind climate from Agrometeorlogical station at Ratchaburi province.

(Source: http://www.aws-observation.tmd.go.th/web/aws/aws_windroses.asp)

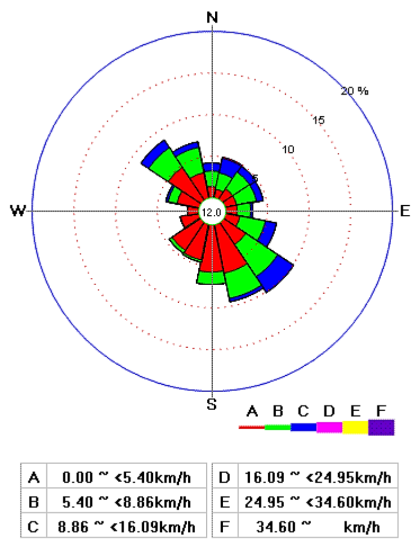


32.RATCHA BURI Agrometeorlogical Station

Date: 2013-01-01 ~ 2013-01-31

%	A	B	C	D	E	F	TOTAL
N	2.0	2.2	0.8	0.0	0.0	0.0	5.0
NNE	1.2	2.3	2.0	0.2	0.0	0.0	5.6
NE	1.3	2.1	1.0	0.0	0.0	0.0	4.4
ENE	1.5	1.7	0.8	0.0	0.0	0.0	4.0
E	1.1	1.2	0.5	0.0	0.0	0.0	2.8
ESE	1.1	1.7	1.2	0.0	0.0	0.0	4.1
SE	2.3	2.5	1.8	0.1	0.0	0.0	6.7
SSE	4.6	1.8	0.3	0.0	0.0	0.0	6.7
S	4.7	1.3	0.1	0.0	0.0	0.0	6.1
SSW	4.6	0.8	0.0	0.0	0.0	0.0	5.4
SW	4.9	1.0	0.0	0.0	0.0	0.0	5.9
WSW	2.7	0.1	0.0	0.0	0.0	0.0	2.8
W	2.0	0.2	0.0	0.0	0.0	0.0	2.3
WNW	3.6	1.9	0.6	0.0	0.0	0.0	6.1
NW	5.9	5.4	1.4	0.0	0.0	0.0	12.7
NNW	5.4	4.1	0.9	0.0	0.0	0.0	10.5
CALM	9.0						
TOTAL	48.9	30.3	11.4	0.4	0.0	0.0	100.0

Appendix Figure 57 Wind climate from Ratchaburi Agrometeorlogical station in January 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average was 9.00 km/h (2.52 m/s). The main direction was NW.



32.RATCHA BURI Agrometeorlogical Station

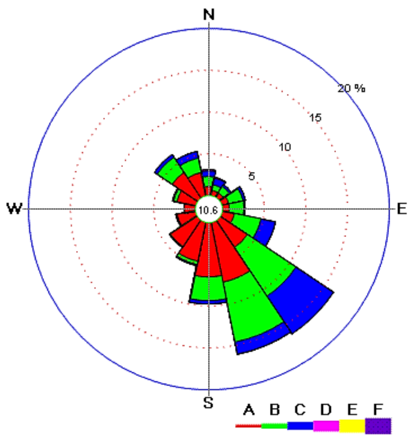
Date: 2013-02-01 ~ 2013-02-28

%	A	B	C	D	E	F	TOTAL
N	1.2	2.0	0.9	0.0	0.0	0.0	4.2
NNE	1.1	2.0	1.8	0.1	0.0	0.0	5.0
NE	1.5	2.4	0.9	0.0	0.0	0.0	4.9
ENE	1.5	2.4	0.8	0.0	0.0	0.0	4.7
E	1.5	1.6	0.3	0.0	0.0	0.0	3.4
ESE	1.9	3.1	1.3	0.0	0.0	0.0	6.4
SE	3.4	4.5	2.3	0.0	0.0	0.0	10.3
SSE	6.0	3.1	0.4	0.0	0.0	0.0	9.6
S	5.8	1.5	0.0	0.0	0.0	0.0	7.4
SSW	4.5	0.2	0.0	0.0	0.0	0.0	4.7
SW	4.1	0.4	0.0	0.0	0.0	0.0	4.6
WSW	2.2	0.0	0.0	0.0	0.0	0.0	2.2
W	1.3	0.0	0.0	0.0	0.0	0.0	1.3
WNW	2.6	1.1	0.3	0.0	0.0	0.0	4.1
NW	4.6	2.9	1.0	0.0	0.0	0.0	8.5
NNW	3.0	3.1	0.7	0.0	0.0	0.0	6.8
CALM	12.0						
TOTAL	46.4	30.4	10.9	0.2	0.0	0.0	100.0

Appendix Figure 58 Wind climate from Ratchaburi Agrometeorlogical station in February 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 12.0 km/h (3.36 m/s). The main direction was SE.

32.RATCHA BURI Agrometeorlogical Station

Date: 2013-03-01 ~ 2013-03-31



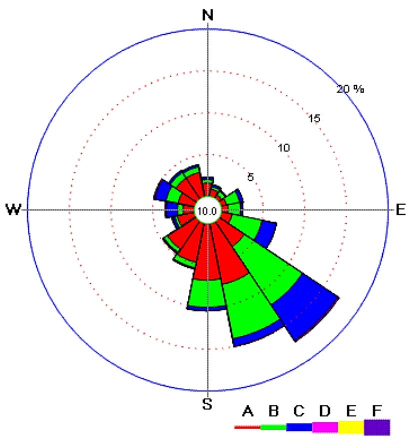
A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

%	A	B	C	D	E	F	TOTAL
N	1.0	1.2	0.7	0.0	0.0	0.0	3.0
NNE	0.7	0.6	0.8	0.0	0.0	0.0	2.2
NE	0.6	0.9	0.3	0.0	0.0	0.0	1.8
ENE	0.9	1.7	0.3	0.0	0.0	0.0	3.0
E	1.0	1.7	0.2	0.0	0.0	0.0	2.9
ESE	1.6	3.3	1.7	0.0	0.0	0.0	6.6
SE	4.0	7.1	5.4	0.1	0.0	0.0	16.5
SSE	7.5	7.2	1.5	0.0	0.0	0.0	16.2
S	6.6	2.8	0.5	0.0	0.0	0.0	9.9
SSW	4.8	0.4	0.1	0.0	0.0	0.0	5.4
SW	3.9	0.1	0.0	0.0	0.0	0.0	4.0
WSW	2.2	0.1	0.1	0.0	0.0	0.0	2.3
W	1.3	0.0	0.0	0.0	0.0	0.0	1.3
WNW	2.2	0.4	0.1	0.0	0.0	0.0	2.7
NW	3.5	2.2	0.4	0.0	0.0	0.0	6.2
NNW	2.8	1.8	0.8	0.0	0.0	0.0	5.4
CALM				10.6			
TOTAL	44.5	31.6	13.0	0.3	0.0	0.0	100.0

Figure 59 Wind climate from Ratchaburi Agrometeorlogical station in March 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 10.6 km/h (2.97 m/s). The main direction was SE.

32.RATCHA BURI Agrometeorlogical Station

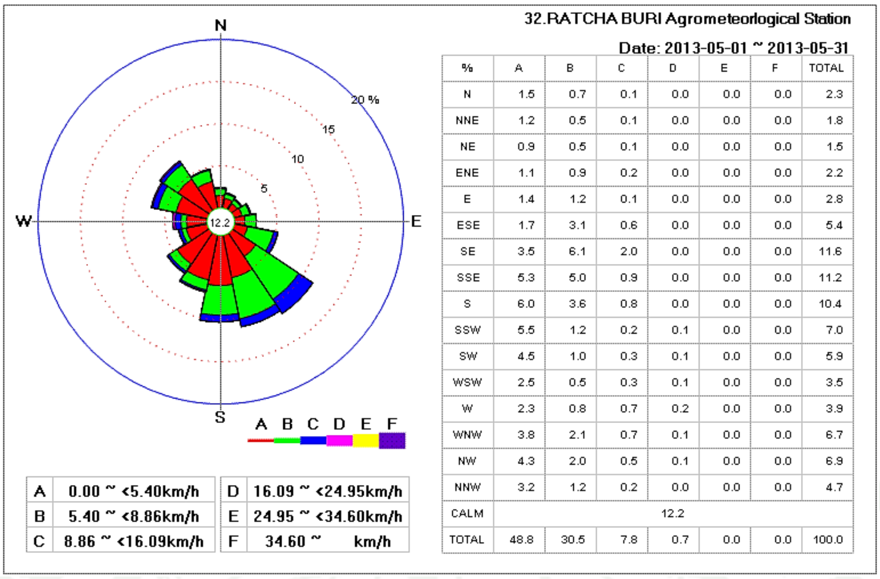
Date: 2013-04-01 ~ 2013-04-30



A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

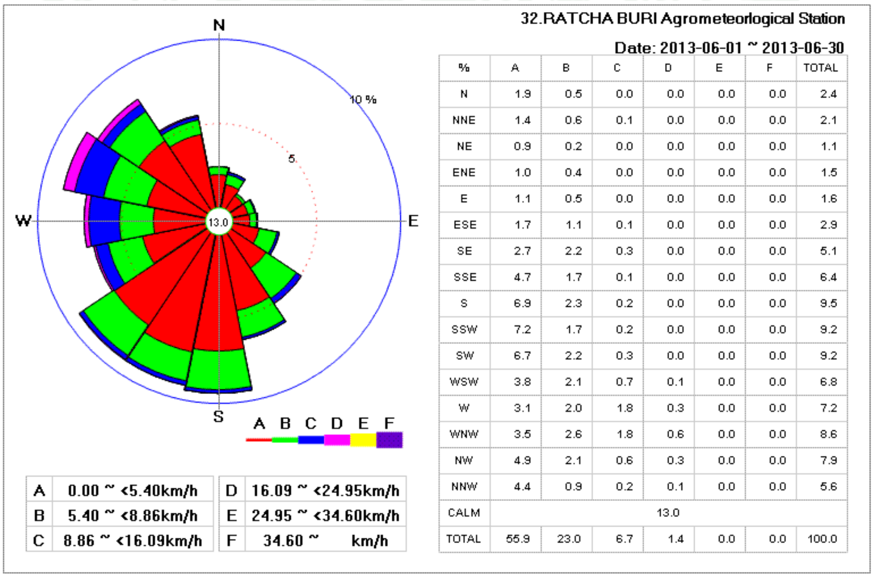
%	A	B	C	D	E	F	TOTAL
N	1.5	0.4	0.3	0.0	0.0	0.0	2.3
NNE	0.9	0.3	0.2	0.0	0.0	0.0	1.4
NE	0.5	0.6	0.1	0.0	0.0	0.0	1.2
ENE	0.8	1.6	0.4	0.0	0.0	0.0	2.8
E	0.9	1.5	0.3	0.0	0.0	0.0	2.7
ESE	1.5	3.6	1.7	0.0	0.0	0.0	6.9
SE	3.8	8.4	5.2	0.0	0.0	0.0	17.4
SSE	7.6	6.5	1.0	0.0	0.0	0.0	15.2
S	6.9	3.3	0.4	0.0	0.0	0.0	10.6
SSW	4.9	0.7	0.2	0.0	0.0	0.0	5.7
SW	4.1	0.5	0.2	0.0	0.0	0.0	4.8
WSW	2.0	0.4	0.3	0.0	0.0	0.0	2.7
W	1.3	0.6	1.4	0.2	0.0	0.0	3.5
WNW	1.9	1.5	1.5	0.1	0.0	0.0	5.0
NW	2.8	0.9	0.2	0.0	0.0	0.0	4.0
NNW	2.9	0.7	0.3	0.0	0.0	0.0	3.9
CALM				10.0			
TOTAL	44.5	31.5	13.5	0.5	0.0	0.0	100.0

Appendix Figure 60 Wind climate from Ratchaburi Agrometeorlogical station in April 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 10.0 km/h (2.8 m/s). The main direction was SE.



%	A	B	C	D	E	F	TOTAL
N	1.5	0.7	0.1	0.0	0.0	0.0	2.3
NNE	1.2	0.5	0.1	0.0	0.0	0.0	1.8
NE	0.9	0.5	0.1	0.0	0.0	0.0	1.5
ENE	1.1	0.9	0.2	0.0	0.0	0.0	2.2
E	1.4	1.2	0.1	0.0	0.0	0.0	2.8
ESE	1.7	3.1	0.6	0.0	0.0	0.0	5.4
SE	3.5	6.1	2.0	0.0	0.0	0.0	11.6
SSE	5.3	5.0	0.9	0.0	0.0	0.0	11.2
S	6.0	3.6	0.8	0.0	0.0	0.0	10.4
SSW	5.5	1.2	0.2	0.1	0.0	0.0	7.0
SW	4.5	1.0	0.3	0.1	0.0	0.0	5.9
WSW	2.5	0.5	0.3	0.1	0.0	0.0	3.5
W	2.3	0.8	0.7	0.2	0.0	0.0	3.9
WNW	3.8	2.1	0.7	0.1	0.0	0.0	6.7
NW	4.3	2.0	0.5	0.1	0.0	0.0	6.9
NNW	3.2	1.2	0.2	0.0	0.0	0.0	4.7
CALM				12.2			
TOTAL	48.8	30.5	7.8	0.7	0.0	0.0	100.0

Appendix Figure 61 Wind climate from Ratchaburi Agrometeorlogical station in May 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 12.2 km/h (3.42 m/s). The main direction was S and SE.

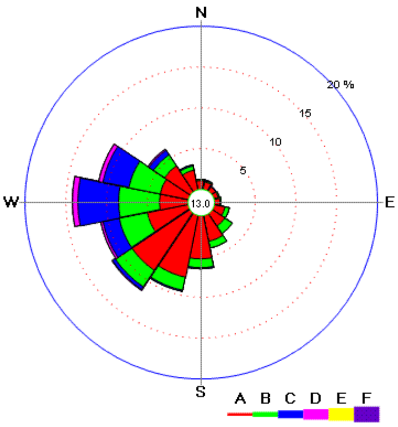


%	A	B	C	D	E	F	TOTAL
N	1.9	0.5	0.0	0.0	0.0	0.0	2.4
NNE	1.4	0.6	0.1	0.0	0.0	0.0	2.1
NE	0.9	0.2	0.0	0.0	0.0	0.0	1.1
ENE	1.0	0.4	0.0	0.0	0.0	0.0	1.5
E	1.1	0.5	0.0	0.0	0.0	0.0	1.6
ESE	1.7	1.1	0.1	0.0	0.0	0.0	2.9
SE	2.7	2.2	0.3	0.0	0.0	0.0	5.1
SSE	4.7	1.7	0.1	0.0	0.0	0.0	6.4
S	6.9	2.3	0.2	0.0	0.0	0.0	9.5
SSW	7.2	1.7	0.2	0.0	0.0	0.0	9.2
SW	6.7	2.2	0.3	0.0	0.0	0.0	9.2
WSW	3.8	2.1	0.7	0.1	0.0	0.0	6.8
W	3.1	2.0	1.8	0.3	0.0	0.0	7.2
WNW	3.5	2.6	1.8	0.6	0.0	0.0	8.6
NW	4.9	2.1	0.6	0.3	0.0	0.0	7.9
NNW	4.4	0.9	0.2	0.1	0.0	0.0	5.6
CALM				13.0			
TOTAL	55.9	23.0	6.7	1.4	0.0	0.0	100.0

Appendix Figure 62 Wind climate from Ratchaburi Agrometeorlogical station in June 2013. Wind speed was 0-24.95 km/h (0-6.99 m/s) and the average wind speed was 13 km/h (3.64 m/s). The main direction was SW, NW and W.

32.RATCHA BURI Agrometeorlogical Station

Date: 2013-07-01 ~ 2013-07-31



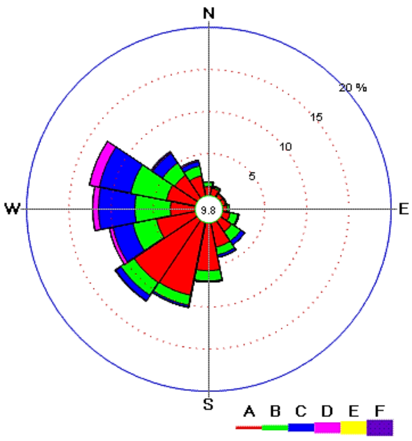
A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

%	A	B	C	D	E	F	TOTAL
N	1.0	0.2	0.0	0.0	0.0	0.0	1.1
NNE	0.9	0.2	0.0	0.0	0.0	0.0	1.1
NE	0.6	0.1	0.0	0.0	0.0	0.0	0.7
ENE	0.6	0.2	0.0	0.0	0.0	0.0	0.8
E	0.8	0.2	0.0	0.0	0.0	0.0	1.0
ESE	1.5	0.5	0.0	0.0	0.0	0.0	2.0
SE	2.0	1.0	0.1	0.0	0.0	0.0	3.2
SSE	3.4	0.7	0.1	0.0	0.0	0.0	4.2
S	5.4	1.1	0.1	0.0	0.0	0.0	6.6
SSW	7.8	1.7	0.1	0.0	0.0	0.0	9.6
SW	8.6	2.4	0.4	0.0	0.0	0.0	11.4
WSW	5.0	3.6	2.1	0.3	0.0	0.0	10.9
W	3.5	4.9	5.1	0.6	0.0	0.0	14.1
WNW	3.4	3.9	3.2	0.6	0.0	0.0	11.2
NW	3.7	1.5	0.7	0.1	0.0	0.0	6.1
NNW	2.3	0.5	0.1	0.0	0.0	0.0	3.0
CALM	13.0						
TOTAL	50.6	22.6	12.2	1.6	0.0	0.0	100.0

Appendix Figure 63 Wind climate from Ratchaburi Agrometeorlogical station in July 2013. Wind speed was 0-24.95 km/h (0-6.99 m/s) and the average wind speed was 13.0 km/h (3.64 m/s). The main direction was W.

32.RATCHA BURI Agrometeorlogical Station

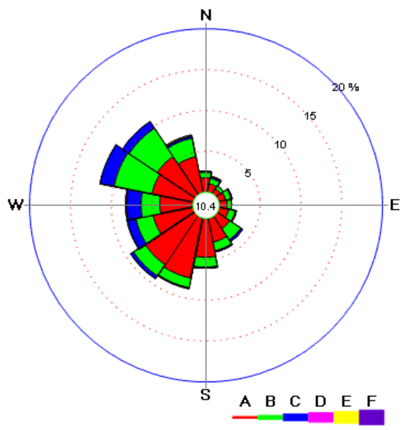
Date: 2013-08-01 ~ 2013-08-31



A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

%	A	B	C	D	E	F	TOTAL
N	1.0	0.5	0.1	0.0	0.0	0.0	1.6
NNE	0.9	0.2	0.0	0.0	0.0	0.0	1.1
NE	0.5	0.1	0.0	0.0	0.0	0.0	0.6
ENE	0.5	0.1	0.0	0.0	0.0	0.0	0.6
E	0.6	0.3	0.0	0.0	0.0	0.0	0.9
ESE	1.1	1.0	0.2	0.0	0.0	0.0	2.2
SE	1.7	1.4	0.5	0.0	0.0	0.0	3.7
SSE	3.2	1.0	0.1	0.0	0.0	0.0	4.3
S	5.9	1.2	0.1	0.0	0.0	0.0	7.2
SSW	8.9	1.3	0.2	0.0	0.0	0.0	10.4
SW	9.0	1.8	0.7	0.1	0.0	0.0	11.6
WSW	4.7	2.7	2.4	0.5	0.0	0.0	10.4
W	2.9	4.1	4.3	0.7	0.0	0.0	12.1
WNW	3.4	4.4	3.7	1.3	0.0	0.0	12.8
NW	3.1	1.8	1.3	0.2	0.0	0.0	6.5
NNW	2.3	1.3	0.6	0.0	0.0	0.0	4.2
CALM	9.8						
TOTAL	49.8	23.2	14.3	2.8	0.0	0.0	100.0

Appendix Figure 64 Wind climate from Ratchaburi Agrometeorlogical station in August 2013. Wind speed was 0-24.95 km/h (0-6.99 m/s) and the average wind speed was 9.8 km/h (2.7 m/s). The main direction was W.



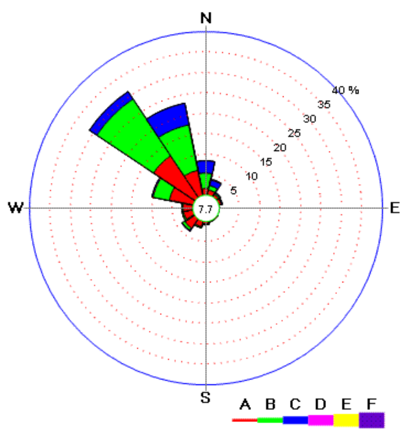
A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

32.RATCHA BURI Agrometeorlogical Station

Date: 2013-09-01 ~ 2013-09-30

%	A	B	C	D	E	F	TOTAL
N	1.7	0.6	0.1	0.0	0.0	0.0	2.5
NNE	1.0	0.6	0.2	0.1	0.0	0.0	1.9
NE	0.7	0.4	0.0	0.0	0.0	0.0	1.1
ENE	1.0	0.7	0.1	0.0	0.0	0.0	1.8
E	1.1	0.5	0.0	0.0	0.0	0.0	1.7
ESE	1.3	0.8	0.1	0.0	0.0	0.0	2.2
SE	2.1	1.6	0.3	0.0	0.0	0.0	3.9
SSE	3.1	1.1	0.1	0.0	0.0	0.0	4.3
S	4.8	1.3	0.1	0.0	0.0	0.0	6.2
SSW	7.6	1.2	0.1	0.0	0.0	0.0	8.9
SW	7.3	1.7	0.4	0.0	0.0	0.0	9.4
WSW	4.9	2.2	1.0	0.1	0.0	0.0	8.2
W	4.0	2.3	1.7	0.2	0.0	0.0	8.2
WNW	5.0	4.7	1.8	0.1	0.0	0.0	11.6
NW	5.4	4.3	0.9	0.1	0.0	0.0	10.7
NNW	4.4	2.2	0.3	0.1	0.0	0.0	7.0
CALM				10.4			
TOTAL	55.5	26.3	7.1	0.7	0.0	0.0	100.0

Appendix Figure 65 Wind climate from Ratchaburi Agrometeorlogical station in September 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 10.4 km/h (2.9 m/s). The main direction was NW.



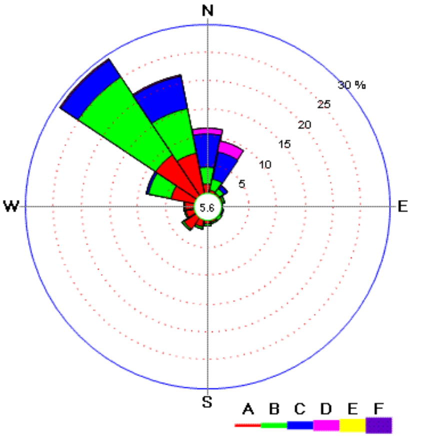
A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

32.RATCHA BURI Agrometeorlogical Station

Date: 2013-11-01 ~ 2013-11-30

%	A	B	C	D	E	F	TOTAL
N	1.5	3.7	3.1	0.1	0.0	0.0	8.4
NNE	1.1	1.1	1.4	0.2	0.0	0.0	3.8
NE	0.7	0.4	0.2	0.0	0.0	0.0	1.3
ENE	0.7	0.2	0.0	0.0	0.0	0.0	1.0
E	0.3	0.0	0.0	0.0	0.0	0.0	0.3
ESE	0.3	0.1	0.0	0.0	0.0	0.0	0.4
SE	0.5	0.0	0.0	0.0	0.0	0.0	0.5
SSE	0.6	0.1	0.0	0.0	0.0	0.0	0.7
S	0.8	0.1	0.1	0.0	0.0	0.0	1.0
SSW	1.5	0.3	0.1	0.0	0.0	0.0	1.9
SW	2.9	0.8	0.1	0.0	0.0	0.0	3.7
WSW	2.3	0.3	0.1	0.0	0.0	0.0	2.7
W	2.2	0.3	0.0	0.0	0.0	0.0	2.5
WNW	5.7	4.2	0.2	0.0	0.0	0.0	10.1
NW	12.0	16.9	2.1	0.0	0.0	0.0	31.0
NNW	6.0	11.3	5.6	0.0	0.0	0.0	23.0
CALM				7.7			
TOTAL	38.8	40.0	13.0	0.4	0.0	0.0	100.0

Appendix Figure 66 Wind climate from Ratchaburi Agrometeorlogical station in November 2013. Wind speed was 0-16.09 km/h (0-4.50 m/s) and the average wind speed was 7.7 km/h (2.16 m/s). The main direction was NW.



32.RATCHA BURI Agrometeorlogical Station

Date: 2013-12-01 ~ 2013-12-31

%	A	B	C	D	E	F	TOTAL
N	1.5	3.1	5.8	1.0	0.0	0.0	11.5
NNE	0.4	2.1	4.9	2.0	0.0	0.0	9.4
NE	0.4	0.9	0.8	0.0	0.0	0.0	2.1
ENE	0.4	0.3	0.0	0.0	0.0	0.0	0.8
E	0.2	0.1	0.0	0.0	0.0	0.0	0.3
ESE	0.3	0.1	0.1	0.0	0.0	0.0	0.5
SE	0.5	0.3	0.1	0.0	0.0	0.0	0.8
SSE	0.6	0.2	0.0	0.0	0.0	0.0	0.8
S	0.9	0.3	0.0	0.0	0.0	0.0	1.1
SSW	1.5	0.2	0.0	0.0	0.0	0.0	1.7
SW	2.6	0.3	0.0	0.0	0.0	0.0	2.9
WSW	1.5	0.2	0.0	0.0	0.0	0.0	1.7
W	1.4	0.3	0.0	0.0	0.0	0.0	1.8
WNW	4.2	3.9	0.4	0.0	0.0	0.0	8.6
NW	8.6	16.6	3.6	0.1	0.0	0.0	29.0
NNW	7.2	8.1	5.9	0.2	0.0	0.0	21.4
CALM	5.6						
TOTAL	32.3	36.9	21.7	3.4	0.0	0.0	100.0

A	0.00 ~ <5.40km/h	D	16.09 ~ <24.95km/h
B	5.40 ~ <8.86km/h	E	24.95 ~ <34.60km/h
C	8.86 ~ <16.09km/h	F	34.60 ~ km/h

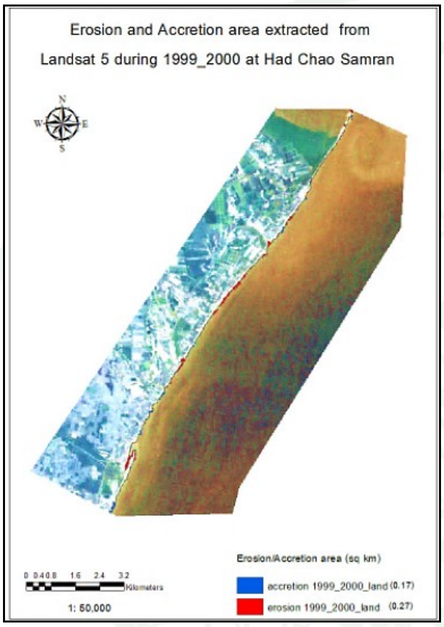
Appendix Figure 67 Wind climate from Ratchaburi Agrometeorlogical station in December 2013. Wind speed was 0-24.95 km/h (0-6.99 m/s) and the average wind speed was 5.6 km/h (1.57 m/s). The main direction was NW.

APPENDIX D

Physical Changes in the Coastal Area

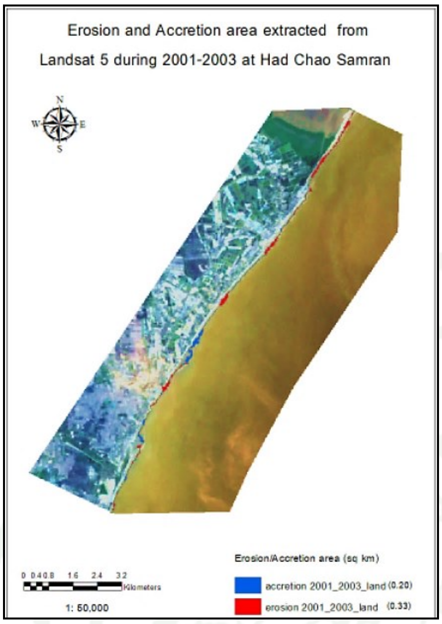
Physical Changes in the Coastal Area

The change in erosion and accretion were also derived from Landsat satellite images from 1999-2011. The change detection maps are as following:

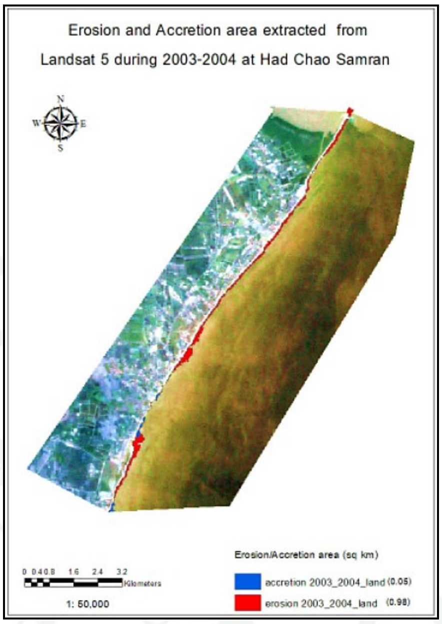


Appendix Figure 68 Erosion area about 0.27 Km^2 and accretion area about 0.17 Km^2 in 1999-2000.

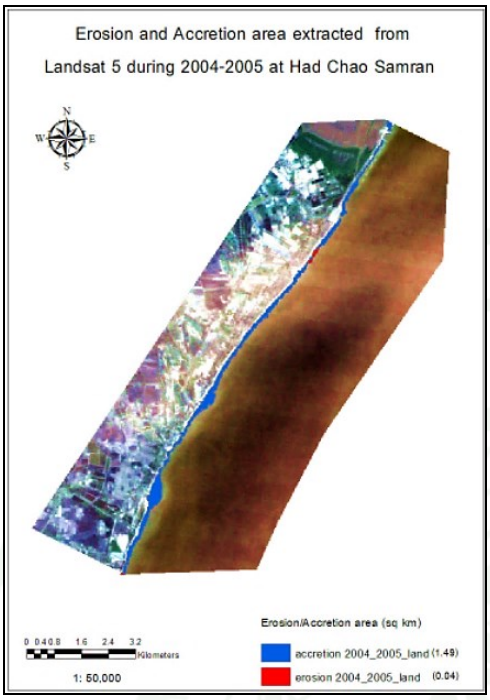
Appendix Figure 69 Erosion area about 0.02 Km^2 and accretion area about 1.02 Km^2 in 2000-2001.



Appendix Figure 70 Erosion area about 0.33 Km^2 and accretion area about 0.23 Km^2 in 2001-2003.



Appendix Figure 71 Erosion area about 0.98 Km^2 and accretion area about 0.05 Km^2 in 2003-2004.

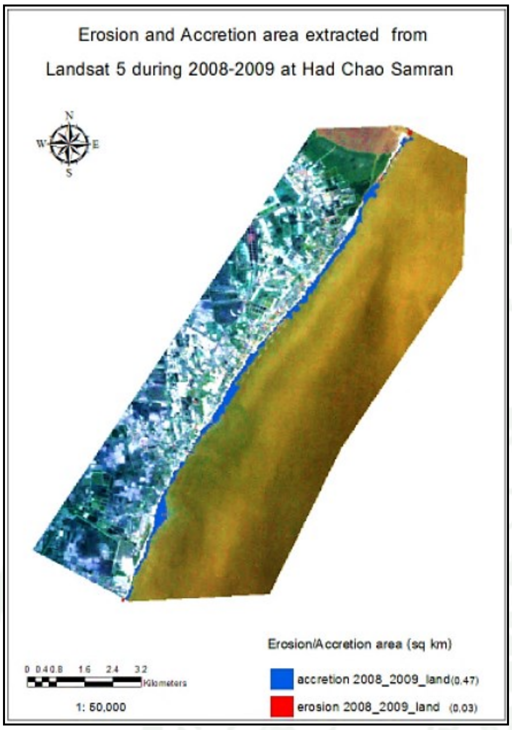


Appendix Figure 72 Erosion area about 0.04 Km^2 and accretion area about 1.49 Km^2 in 2004-2005.

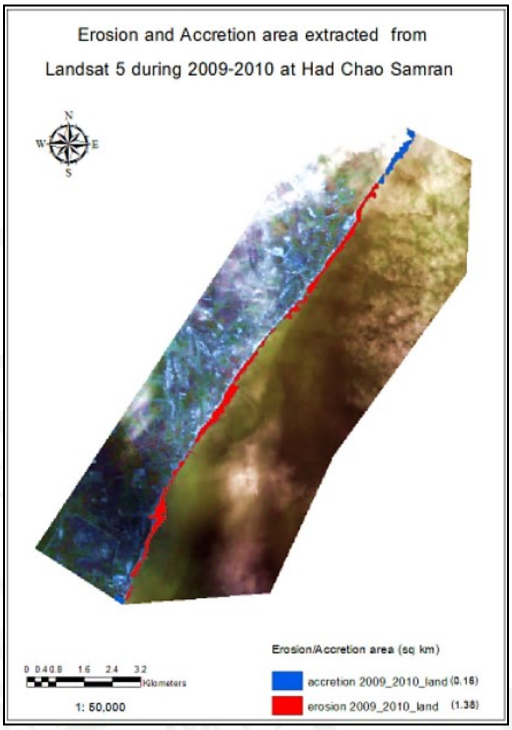
Appendix Figure 73 Erosion area about 1.36 Km^2 and accretion area about 0.06 Km^2 in 2005-2006.

Appendix Figure 74 Erosion area about 0.34 Km^2 and accretion area about 0.18 Km^2 in 2006-2007.

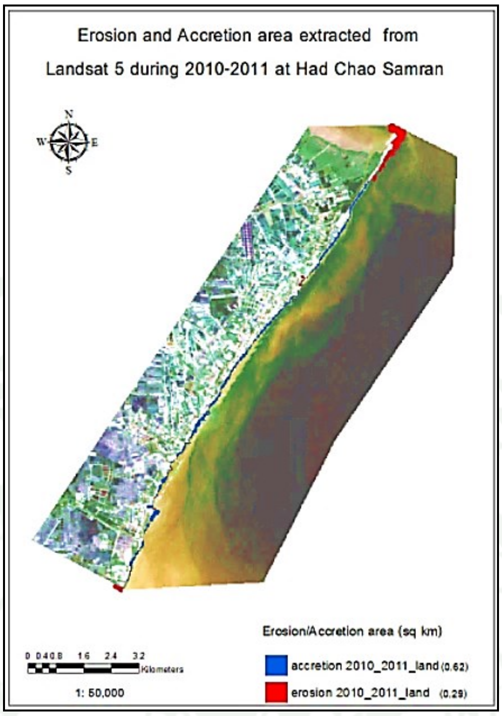
Appendix Figure 75 Erosion area about 0.24 Km^2 and accretion area about 0.28 Km^2 in 2007-2008.



Appendix Figure 76 Erosion area about 0.03 Km^2 and accretion area about 1.47 Km^2 in 2008-2009.



Appendix Figure 77 Erosion area about 1.38 Km^2 and accretion area about 0.16 Km^2 in 2009-2010.



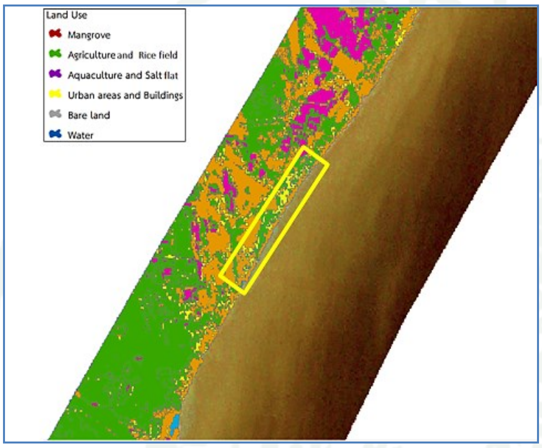
Appendix Figure 78 Erosion area about 0.29 Km^2 and accretion area about 0.62 Km^2 in 2010-2011.

APPENDIX E

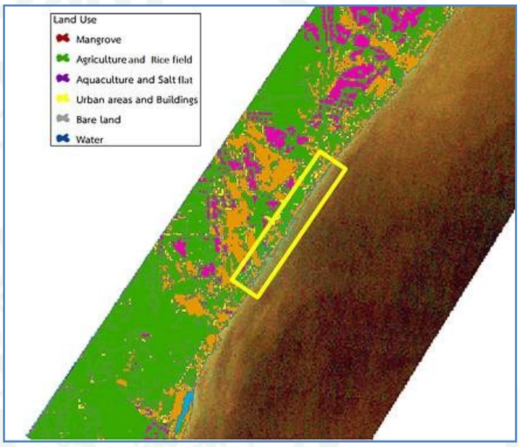
Settlement of Community

Settlement of Community

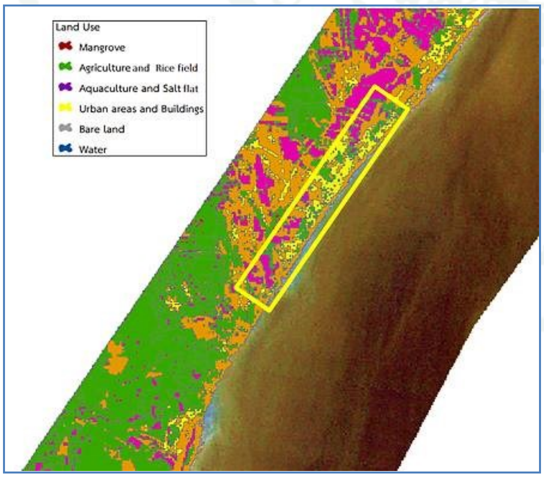
The impact to social aspect will be focused on the risk analysis from coastal erosion in settlement of community. Urban area changed gradually from 1991 to 2011. The population migration increased markedly in the middle part and moved southward of the shore during 2004-2011.



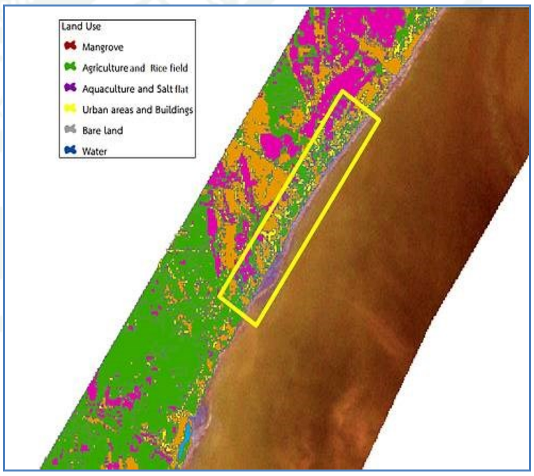
Appendix Figure 79 Urban area in 1999



Appendix Figure 80 Urban area in 2000

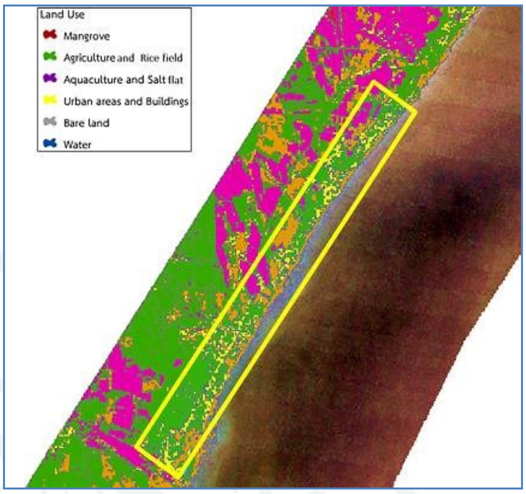


Appendix Figure 81 Urban area in 2001

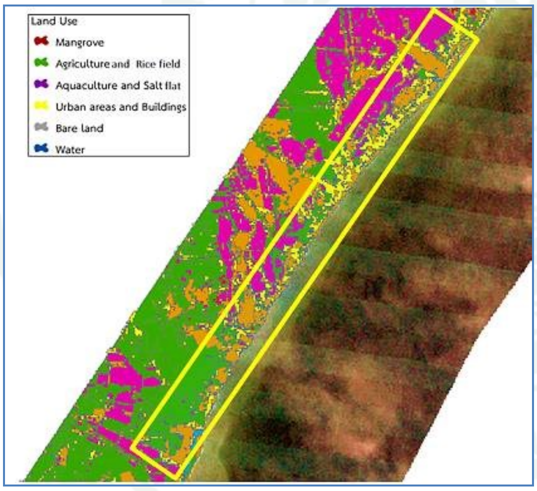


Appendix Figure 82 Urban area in 2003

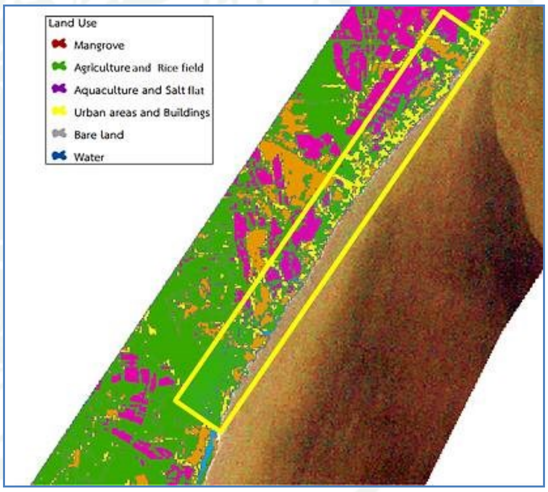
Appendix Figure 83 Urban area in 2004



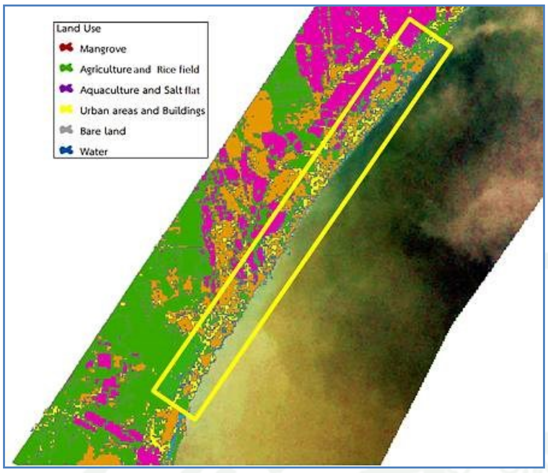
Appendix Figure 84 Urban area in 2005



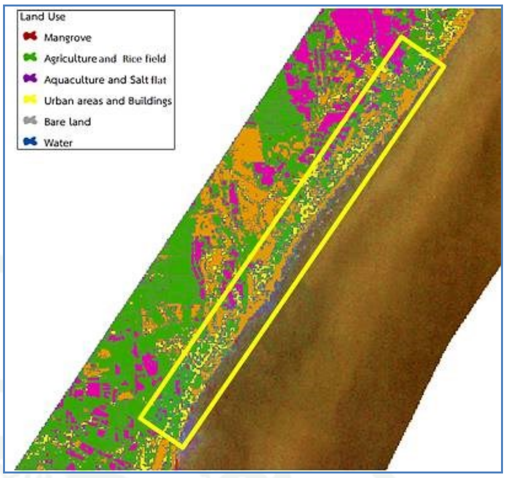
Appendix Figure 85 Urban area in 2006



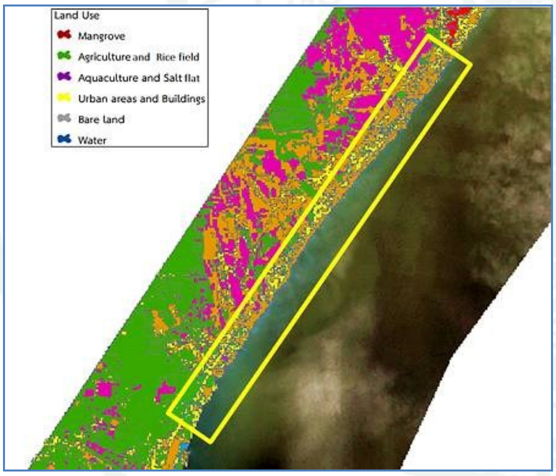
Appendix Figure 86 Urban area in 2007



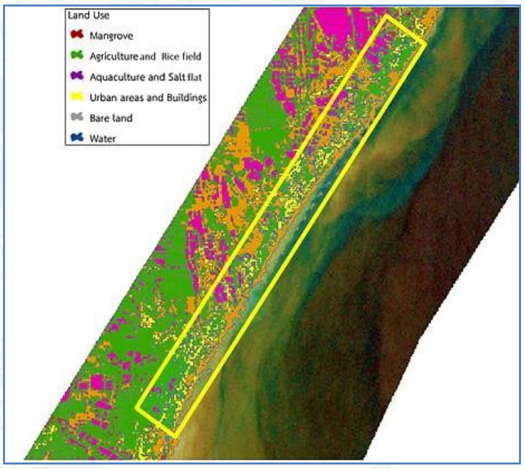
Appendix Figure 87 Urban area in 2008



Appendix Figure 88 Urban area in 2009



Appendix Figure 89 Urban area in 2010



Appendix Figure 90 Urban area in 2011

APPENDIX F

Phyton Script of Spatial Coastal Risk Model

```
PythonWin 2.7.2 (default, Jun 12 2011, 15:08:59) [MSC v.1500 32 bit (Intel)] on
win32.
Portions Copyright 1994-2008 Mark Hammond - see 'Help/About PythonWin' for
further copyright information.
>>>
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Erosion risk.py
# Created on: 2015-02-01 11:21:31.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Erosion risk <Input_Erosion_Accretion_Rate> <Value_field>
<Physical_Ranking> <Input_Erosion_Price> <Value_field__2_>
<Economic_Ranking> <Input_Buffer_Away_From_The_Shore> <Value_field__3_>
<Social_Ranking> <Erosion_Risk>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("3D")
arcpy.CheckOutExtension("spatial")

# Script arguments
Input_Erosion_Accretion_Rate = arcpy.GetParameterAsText(0)
if Input_Erosion_Accretion_Rate == '#' or not Input_Erosion_Accretion_Rate:
    Input_Erosion_Accretion_Rate = "Rate_polygon" # provide a default value if
unspecified

Value_field = arcpy.GetParameterAsText(1)
if Value_field == '#' or not Value_field:
```

```
    Value_field = "CODE" # provide a default value if unspecified

Physical_Ranking = arcpy.GetParameterAsText(2)
if Physical_Ranking == '#' or not Physical_Ranking:
    Physical_Ranking = "D:\\Erosion Risk Map\\Physical_ranking.tif" # provide a
default value if unspecified

Input_Erosion_Price = arcpy.GetParameterAsText(3)
if Input_Erosion_Price == '#' or not Input_Erosion_Price:
    Input_Erosion_Price = "erosion_1999_2011_price" # provide a default value if
unspecified

Value_field__2_ = arcpy.GetParameterAsText(4)
if Value_field__2_ == '#' or not Value_field__2_:
    Value_field__2_ = "Area_price" # provide a default value if unspecified

Economic_Ranking = arcpy.GetParameterAsText(5)
if Economic_Ranking == '#' or not Economic_Ranking:
    Economic_Ranking = "D:\\Erosion Risk Map\\Economic_price_ranking.tif" #
provide a default value if unspecified

Input_Buffer_Away_From_The_Shore = arcpy.GetParameterAsText(6)
if Input_Buffer_Away_From_The_Shore == '#' or not
Input_Buffer_Away_From_The_Shore:
    Input_Buffer_Away_From_The_Shore = "Shoreline2011_buffer5" # provide a
default value if unspecified

Value_field__3_ = arcpy.GetParameterAsText(7)
if Value_field__3_ == '#' or not Value_field__3_:
    Value_field__3_ = "distance" # provide a default value if unspecified

Social_Ranking = arcpy.GetParameterAsText(8)
```

```
if Social_Ranking == '#' or not Social_Ranking:
    Social_Ranking = "D:\\Erosion Risk Map\\Social_ranking.tif" # provide a default value if unspecified

Erosion_Risk = arcpy.GetParameterAsText(9)
if Erosion_Risk == '#' or not Erosion_Risk:
    Erosion_Risk = "D:\\Erosion Risk Map\\Erosion_Risk.tif" # provide a default value if unspecified

# Local variables:
Physical_Factor__tif = Value_field
Physical_Factor_tif = Physical_Factor__tif
Cellsize = "2"
Erosion_Risk__tif = Physical_Ranking
Reclassification = "1 1;1 2 2;2 3 3"
Economic_price_tif = Input_Erosion_Price
Economic_price_ranking__tif = Economic_price_tif
Cellsize__2_ = "2"
Reclassification__2_ = "1.2371403771864813e-320 50000000 1;50000000 100000000 2;100000000 905037824 3"
lu_buffer__tif = Input_Buffer_Away_From_The_Shore
lu_buffer_tif = lu_buffer__tif
Cellsize__3_ = "2"
Reclassification__3_ = "0 50 3;50 100 2;100 150 1"

# Process: Polygon to Raster
arcpy.PolygonToRaster_conversion(Input_Erosion_Accretion_Rate, Value_field, Physical_Factor__tif, "CELL_CENTER", "NONE", Cellsize)

# Process: Set Null (2)
arcpy.gp.SetNull_sa(Physical_Factor__tif, Physical_Factor__tif, Physical_Factor_tif, "\"VALUE\" < 1")
```

```
# Process: Reclassify
arcpy.Reclassify_3d(Physical_Factor_tif, "VALUE", Reclassification,
Physical_Ranking, "DATA")

# Process: Polygon to Raster (2)
arcpy.PolygonToRaster_conversion(Input_Erosion_Price, Value_field__2_,
Economic_price_tif, "CELL_CENTER", "NONE", Cellsize__2_)

# Process: Reclassify (2)
arcpy.Reclassify_3d(Economic_price_tif, "Value", Reclassification__2_,
Economic_price_ranking__tif, "DATA")

# Process: Set Null
arcpy.gp.SetNull_sa(Economic_price_ranking__tif, Economic_price_ranking__tif,
Economic_Ranking, "\"VALUE\" < 1")

# Process: Polygon to Raster (3)
arcpy.PolygonToRaster_conversion(Input_Buffer_Away_From_The_Shore,
Value_field__3_, lu_buffer__tif, "CELL_CENTER", "NONE", Cellsize__3_)

# Process: Set Null (3)
arcpy.gp.SetNull_sa(lu_buffer__tif, lu_buffer__tif, lu_buffer_tif, "\"VALUE\" < 1")

# Process: Reclassify (3)
arcpy.Reclassify_3d(lu_buffer_tif, "Value", Reclassification__3_, Social_Ranking,
"DATA")

# Process: Cell Statistics
arcpy.gp.CellStatistics_sa("'D:\\Erosion Risk Map\\Physical_ranking.tif';'D:\\Erosion
Risk Map\\Economic_price_ranking.tif';'D:\\Erosion Risk Map\\Social_ranking.tif'",
Erosion_Risk__tif, "SUM", "DATA")
```

```
# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Erosion_Risk__tif, "Value", "1 3 1;3 6 2;6 9 3",
Erosion_Risk, "DATA")
```

BIOGRAPHICAL DATA

NAME:	Mrs. Siriluk Prukpitikul
DATE OF BIRTH:	November 13, 1968
PLACE OF BIRTH:	Surat Thani Province
GRADUATION:	M.sc. (Marine Biology) Norwegian University of Science and Technology (NTNU)
CURRENT POSITIONS	Chief of Natural Resources Division, Geo-informatics Applications and Services Office, Geo-informatics and Space Technology Development Agency (GISTDA)
RESEARCH/ACADEMIC PUBLISHED	

1. Prukpitikul, S., P. Narangjavana, and R. Tokrisna. 2014. Spatial Analysis for Coastal Zone Changes Related to Land Utilization. International Journal of Development and Sustainability. 3(8): 1629-1647.
2. Prukpitikul S., P. Narangjavana, and R. Tokrisna. 2014. Assessment of the Effects of Community Expansion and Land Use Transformation on a Coastal Area in Thailand. ICESR 2014: December 13-14, Kuala Lumpur, Malaysia.