COMPARATIVE STUDY OF THE EASTERN AND WESTERN COASTAL CHANGE OF THE PENINSULA THAILAND

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geotechnology

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การศึกษาเชิงเปรียบเทียบของการเปลี่ยนแปลงชายฝั่งตะวันออกและตะวันตก ของคาบสมุทรไทยตอนล่าง

นางสาวนำพร วัฒนธร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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พื้นที่การศึกษาครั้งนี้ตั้งอยู่ในบริเวณภาคใต้ของประเทศไทย ทางด้านชายฝั่งทะเลอ่าวไทยจะครอบคลุมพื้นที่จังหวัดสุราษฎร์ธานี จังหวัดนครศรีธรรมราช และจังหวัดสงขลา และชายฝั่งทะเลอันดามันครอบคลุมพื้นที่จังหวัดกระบี่ จังหวัดตรัง และจังหวัดสตูล

การศึกษาการเปลี่ยนแปลงชายฝั่งได้ใช้เทคนิคการรับรู้ระยะไกล ระบบสารสนเทศทางภูมิศาสตร์ และการศึกษาภาคสนาม ซึ่งในการศึกษาครั้งนี้ได้ใช้ข้อมูลภาพถ่ายดาวเทียม Landsat TM, Landsat ETM, SPOT และ THEOS ในช่วงเวลาที่แตกต่างกัน การหาอัตราส่วนระหว่างแบนด์ (Band Ratio)ของแบนด์อินฟาเรดช่วงสั้นและแบนด์สีเขียว และการหาค่าดัชนีความแตกต่างของน้ำ (NDWI : (แบนด์สีเขียว – แบนด์อินฟาเรดช่วงสั้น) / (แบนด์สีเขียว + แบนด์อินฟาเรดช่วงสั้น)) เป็นวิธีการศึกษาที่สามารถแสดงพื้นที่ที่เป็นผืนน้ำและพื้นที่ที่เป็นแผ่นดินได้อย่างชัดเจน มีการประยุกต์ใช้ค่าดัชนีความแตกต่างของน้ำ (NDWI) ในการจำแนกประเภทข้อมูลแบบโครงสร้างต้นไม้ตัดสินใจ (Decision Tree Classification) ซึ่งการจำแนกข้อมูลดังกล่าวจะทำให้สามารถแสดงแนวชายฝั่งทะเลได้อย่างชัดเจน การสร้างแผนที่ธรณีสัณฐานชายฝั่งได้ใช้วิธีการจำแนกประเภทข้อมูลแบบกำกับดูแล (Supervised Classification) ในโปรแกรม ENVI และการศึกษาภาคสนาม

การสร้างแผนที่แนวชายฝั่งทะเลจากการจำแนกพื้นดินและพื้นน้ำใน 2 ช่วงเวลาโดยการใช้เทคนิคการรับรู้ระยะไกลนั้น ผลการศึกษาพบว่า การกัดเซาะชายฝั่งในชายฝั่งด้านอ่าวไทยมีความรุนแรงและมีผลกระทบมากกว่า 230 กิโลเมตร ตลอดแนวชายฝั่งตั้งแต่จังหวัดสุราษฎร์ธานี ที่พบการกัดเซาะชายฝั่งเกิดขึ้นมากในพื้นที่อำเภอดอนสักโดยมีอัตราการกัดเซาะคิดเป็นระยะทาง 1.32 เมตรต่อปี ในช่วงปี พ.ศ. 2544 ถึงปี พ.ศ. 2552 การกัดเซาะชายฝั่งในจังหวัดนครศรีธรรมราช พบได้อย่างเด่นชัดตลอดตามแนวถนนเลียบชายฝั่งสายปากพนัง – หัวไทร และในจังหวัดสงขลาพบการกัดเซาะมากในพื้นที่อำเภอระโนด อัตราการกัดเซาะชายฝั่งของทั้งสองพื้นที่คิดเป็นระยะทาง 8.79 เมตรต่อปี ในช่วงปี พ.ศ. 2547 ถึงปี พ.ศ. 2550 และ1.93 เมตรต่อปี ในช่วงปี พ.ศ. 2545 ถึงปี พ.ศ. 2552 ตามลำดับ ชายฝั่งทะเลอันดามันมีการเปลี่ยนแปลงค่อนข้างน้อย ซึ่งการเปลี่ยนแปลงชายฝั่งทะเลส่วนใหญ่เป็นแบบชายฝั่งคงสภาพ แต่ก็มีการกัดเซาะชายฝั่งเกิดร่วมด้วยในพื้นที่หาดทรายที่อยู่ด้านนอกสุด การกัดเซาะชายฝั่งในจังหวัดกระบี่เกิดขึ้นมากในพื้นที่สุสานหอยบ้านแหลมโพธิ์ ซึ่งพบว่ามีอัตราการกัดเซาะคิดเป็นระยะทาง 1.32 เมตรต่อปี ในช่วงปี พ.ศ. 2532 ถึงปี พ.ศ. 2544

การกัดเซาะชายฝั่งในจังหวัดตรังจะพบการกัดเซาะชายฝั่งเกิดขึ้นตลอดแนวชายฝั่งของอำเภอสิเกา และจังหวัดสตูลจะพบมากในพื้นที่อำเภอละงู โดยมีอัตราการกัดเซาะคิดเป็นระยะทาง 1.04 เมตรต่อปี ในช่วงปี พ.ศ. 2544 ถึงปี พ.ศ. 2549 และ 1.59 เมตรต่อปี ในช่วงปี พ.ศ. 2545 ถึงปี พ.ศ. 2550 ตามลำดับ ในการศึกษาได้จำแนกธรณีสัณฐานชายฝั่งทะเล โดยที่ด้านอ่าวไทยได้จำแนกธรณีสัณฐานชายฝั่งทะเลออกได้ดังนี้คือ ที่ราบน้ำขึ้นถึงเดิม ที่ราบน้ำขึ้นถึง ที่ราบใต้ระดับน้ำลง ลากูนเดิม ลากูนปัจจุบัน พรุ หาดทรายเดิม และหาดทรายปัจจุบัน ส่วนในชายฝั่งทะเลด้านอันดามันจำแนกเป็นชายฝั่งหิน ที่ราบน้ำขึ้นถึง และหาดทรายปัจจุบัน

จากผลการศึกษาเชิงเปรียบเทียบพบว่า การเปลี่ยนแปลงชายฝั่งทะเลด้านอ่าวไทยมีผลกระทบมากกว่าบริเวณชายฝั่งทะเลอันดามัน โดยในพื้นที่ชายฝั่งทะเลด้านอ่าวไทยส่วนใหญ่กลายเป็นพื้นที่เพาะเลี้ยงสัตว์น้ำ พื้นที่ที่เคยเป็นป่าชายเลนได้แปรเปลี่ยนไปเป็นนากุ้ง ซึ่งเป็นสาเหตุสำคัญที่มีผลต่อการกัดเซาะชายฝั่ง ส่วนในพื้นที่ชายฝั่งทะเลอันดามันนั้น ยังได้รับการปกป้องจากแนวป่าชายเลน ที่มีอยู่อย่างหนาแน่นในพื้นที่ที่ราบน้ำขึ้นถึง และอาจจะมีการกัดเซาะได้ในบางพื้นที่ในช่วงหน้ามรสุม

สาขาวิชา เทคโนโลยีธรณี

ปีการศึกษา 2557

ลายมือชื่อนักศึกษา______

ลายมือชื่ออาจารย์ที่ปรึกษา______

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม______

NAMPORN WATTANATON : COMPARATIVE STUDY OF THE EASTERN AND WESTERN COASTAL CHANGE OF THE PENINSULA THAILAND. THESIS ADVISOR : CHONGPAN CHONGLAKMANI, Ph.D., 208 PP.

COASTAL CHANGE/GEOMORPHOLOGY/FIELD GEOLOGY / REMOTE SENSING/GIS/NDWI/DECISION TREE CLASSIFICATION

The study areas cover coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea.

The remote sensing technique, GIS and field investigation are employed in the coastal change study. The satellite images acquired in different times of Landsat TM, Landsat ETM^{+}, SPOT and THEOS are used in this study. The band ratio of SWIR / GREEN and NDWI (GREEN - NIR) / (GREEN + NIR) methods would reveal the water body and the land body. The NDWI value is applied in decision tree classification which is used for indicating the coastline. The geomorphological map was created by using the supervised classification method in ENVI (The Environment for Visualizing Images) program and field investigation.

The classification of land and water and the mapping of coastline of two periods have been accomplished by using the remote sensing technique. The coastal erosion of the Gulf of Thailand is severe and affected more than 230 kilometers long. In Surat Thani province the main coastal erosion area covers the Don Sak district with the rate of 1.32 meters per year during 2001 to 2009. The prominent coastal erosion of the Nakhon Si Thammarat province is along the Pak Panang – Hua Sai road and it is occurred in the Ranod district coast of the Songkhla province. The rate of erosion of the two areas is 8.79 meters per year during 2004 to 2007 and 1.93 meters per year during 2002 to 2009 respectively. The results of the study reveal only little change for the Andaman Sea coast. The coastal change is almost stable coast but the coastal erosion is evident in the young sandy beach. In Krabi province the coastal erosion is obvious in the Laem Pho Shell Cemetery of Muang district with the rate of 1.32 meters per year during 1989 to 2001. The coastal erosion of Trang and Satun provinces is evident in the Sikao and the La Ngu districts with the rate of 1.04 meters per year during 2001 to 2006 and 1.59 meters per year during 2002 to 2007 respectively. The result of the geomorphological study indicates that the Gulf of Thailand coast is characterized by old tidal flat, intertidal flat, sub – tidal flat, old and young lagoons, marsh, old and young sandy beach. The Andaman sea coast is represented by rocky coast, intertidal flat and young sandy beach.

The comparison of the coastal change shows that the coastal erosion of the Gulf of Thailand is more severe than the Andaman Sea coast. Most of the Gulf of Thailand coast is now used for aquaculture where the former mangrove coast has been replaced by the shrimp ponds which are sensitive to erosion. Along the Andaman Sea coast, the erosion is protected by the remaining mangrove swamp and it is occurred only in local area during the seasonal storms.

School of Geotechnology — Student's Signature Namporn Wattanaton

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Co – Advisor's Signature ______

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Namporn Wattanaton

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

CHAPTER 1

INTRODUCTION

1.1 Introduction to this Study

Global warming has drawn strong public attention worldwide because it induces changes in climate and sea – level. It consequently has direct impacts on the coastal zone of every countries including Thailand. Thailand comprises extensive coastline totaling about 2,637 km in length (DMR, 2002). The coasts are bordered by the Gulf of Thailand and the Andaman Sea. These coastal zones are endowed with rich natural resources and are, therefore, important for economic development of the country.

At present, the coasts of Thailand have been severely changed. The coastal problems caused by the changes include beach pollution, coastal erosion, reduction of coastal wetland, and reduction in sediment supply. These problems point to an increasingly degraded coastal environment. Natural processes and human activities are considered as factors of global warming, resulting in sea – level rise. But the magnitude of sea – level rise are still controversial as the geologic processes and the tectonic setting are different in each coastal zone.

Preliminary study of the coastal changes of Thailand has been carried out by the Department of Mineral Resources (DMR) since 2002. It indicates that, around the Gulf of Thailand, 10.64 % of the total 1,700 km in length has been severely eroded (> 5 m per year) and 17.74 % under moderate erosion (1 – 5 m per year).

Along the 937 km long Andaman Sea coast, about 2.45 % has been under severe erosion and 9.65 % under moderate erosion. The causes are attributed to human activities by extensive community development, less influx of sediments from land areas, monsoon and tropical winds, plate movement, and sea level change from green house effect.

Consequently, it is necessary to study the coastal change in order to better understand the causes of changes in both the Andaman Sea coast and the Gulf of Thailand coast. The conclusion and information gained from the study are important for formulation of the action plan for protection and mitigation of the hazards caused by the coastal changes.

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

1.2 Objective of Research

The research emphasizes the physical changes and disaster of coastal areas which cause severe impact on economy and social and coastal resources. The main purposes of the study are:

1. The general understanding of the methodology for coastal change detection and cause of coastal change.

2. The comparison of coastal change along the Gulf of Thailand coast and the Andaman sea coast.

3. A coastal geomorphology map of the study area.

1.3 Scope and Limitation of Research

This research integrates remote sensing, GIS techniques and field investigation. The analysis focuses on the relationship between existing coastal change and physical factors caused mainly by natural processes. The study areas cover coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea.

1.4 Characterization of the Study Area

1.4.1 Location

The study area is situated in the southern part of Thailand. It is located along the coast in the Gulf of Thailand sea coast and the Andaman Sea coast and it situated within the Surat Thani, Nakhon Si Thammarat, Songkhla, Krabi, Trang, and Satun Province (Figure 1.1). The largest river of the south is the Tapi in Surat Thani and the middle of the peninsula is several mountain chains, with the highest elevation at the 1,835 m high Khao Luang in the Nakhon Si Thammarat Province.

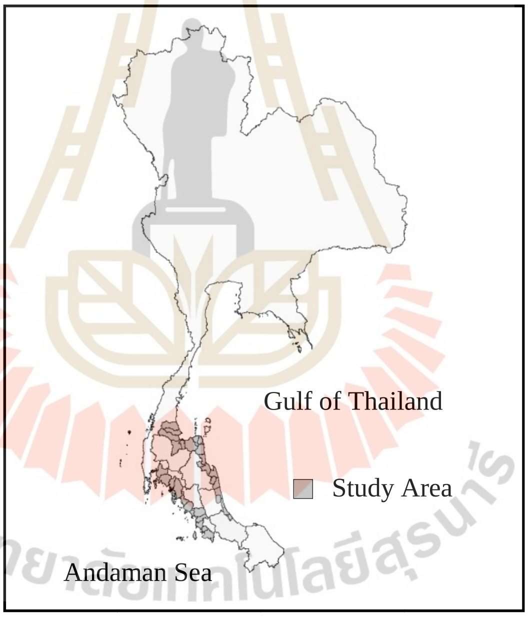


Figure 1.1 Study areas of Thailand coastline.

1.4.2 Topography

The topography of southern Thailand is the peninsula between the Andaman Sea which is on the western side of the part and the South China Sea which is on the eastern side. The long ridge of western mountains in the Northern and

Central also extend to Southern Thailand. Phuket ridge along the west coast and Nakhon Si Thammarat ridge in the central of lower portion forming the backbone of the southern part separate this part into two regions, the Gulf of Thailand coast and the Andaman sea coast these has long coastline including more than 2,600 kilometers. Topography of east and west coast are differences as follows:

Emergent coastline: The Gulf of Thailand coast is an emergent coastline, which is stretches along the coast that have been exposed by the sea due to a relative fall in sea levels. These are characterized by a broad coastal plain with sand bars, beach ridges and cheniers occurring in Nakhon Si Thammarat and Songkhla provinces. Tidal flats with large lagoons and sand spits are also common along the east coast as well as pro – delta deposition at the mouth of the Tapir River in the Surat Thani provinces.

Submergent coastline: The Andaman Sea coast is a submergent coastline, which is stretches along the coast that have been inundated by the sea due to a relative rise in sea levels. These are characterized by numerous islands, drowned valleys, steep cliffed and truncated headlands, and small coves or embayments. Embayments are backed by short and narrow beaches, distinctive crescent shape beach ridges, and steep narrow floodplains with thin deposits of Quaternary sediments formed by the short, steep – gradient swift rivers that flow into the Andaman Sea.

1.4.3 Climate

The climate of Thailand is under the influence of monsoon winds of seasonal character i.e. southwest monsoon and northeast monsoon. The southwest monsoon which starts in May brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially the windward side of the mountains. The northeast monsoon which starts in October brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand. In the southern part, this monsoon causes mild weather and abundant rain along the eastern coast of the part. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid – May and ends in mid – October while northeast monsoon normally starts in mid – October and ends in mid – February.

Rainy season in the southern part is different from upper Thailand. Abundant rain occurs during both the southwest and northeast monsoon periods. During the southwest monsoon the southern Thailand west coast receives much rainfall and reaches its peak in September. On the contrary, much rainfall in the southern Thailand east coast which its peak is in November remains until January of the following year which is the beginning of the northeast monsoon.

1.5 Geological Setting

In the southern of Thailand is underlain by rocks ranging in age from Pre – Cambrian to Quaternary. Geologic maps at scales of 1:250,000 and 1:1,000,000 of the study areas were issued by Department of Mineral Resources (1982, 1983). The Geological map of study areas is shown in Figure 1.2.

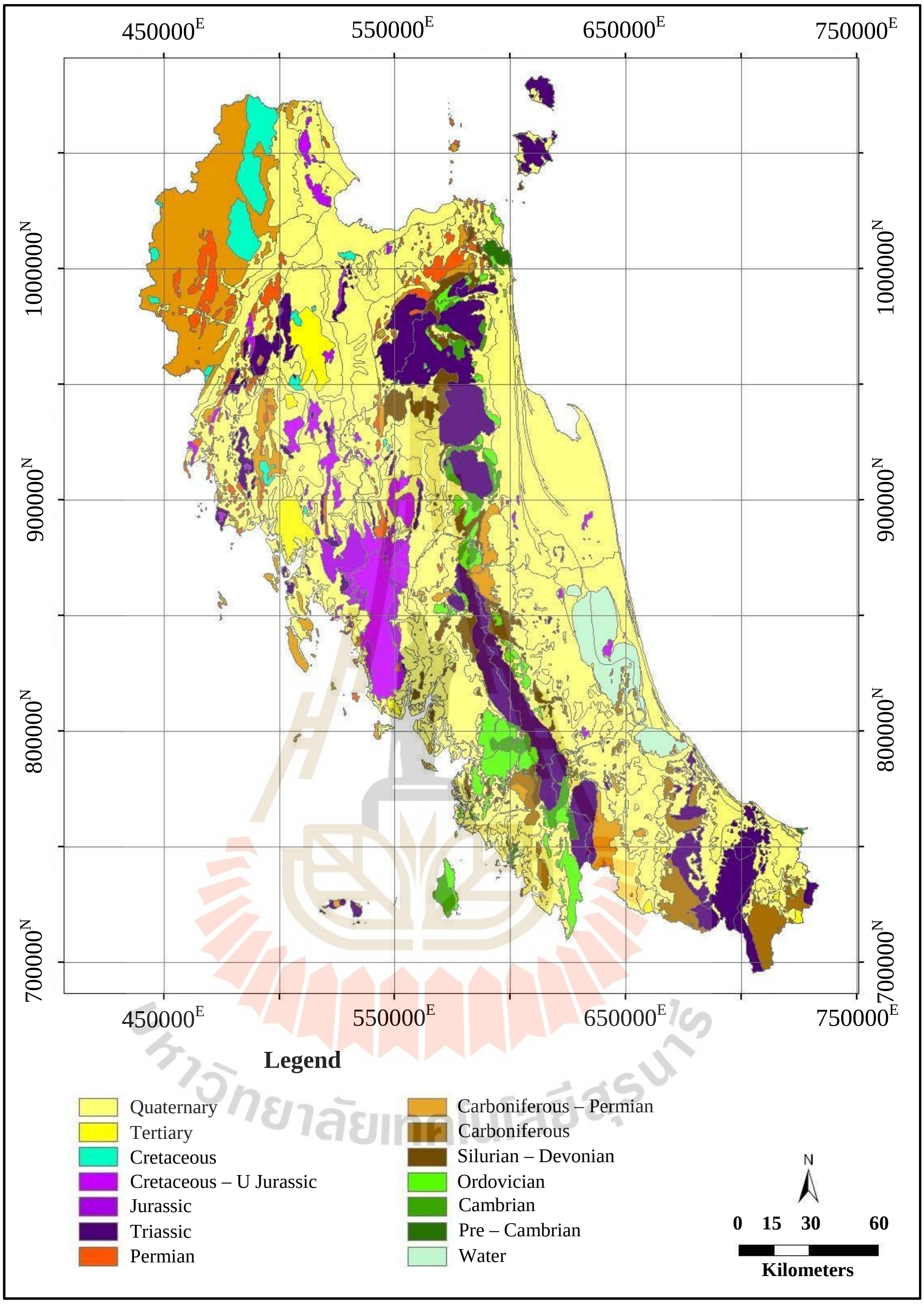


Figure 1.2 Geologic map of study area.

1.5.1 General Geology

Pre – Cambrian consists of gneiss and mica – schist. Paleozoic consists of sandstone, limestone with siltstone, shale, conglomerate shale and massive limestone. Mesozoic including Triassic consists of marine sediments of sandstone, siltstone and shale. Jurassic – Cretaceous consists of terrigenous sediments of sandstone, and shale. Cenozoic consists of Tertiary basins including Kean Sa basin, Sin Pun basin, Krabi basin, Sa Dao basin and Saba Yoi basin. Quaternary consist sediment of sand, gravel and Tin

1.5.2 Stratigraphy

1) Pre – Cambrian

High – grade metamorphic rocks in the Thai peninsular were also reported in Sichon and Kanom district, Nakhon Si Thammarat province (Nakinbordi et al., 1985). The late study of Kosuwan (1996) added more information about the rock unit this area. These studies divide the rocks in to two rock units from old to young; Ni Plaw gneiss rock unit actually contains intertwined layer of biotite gneiss and sillimanite gneiss. Kao Yoi rock unit contains of schist, quartzite, small lens of calcsilicate and marble.

2) Lower Paleozoic

Cambrian: The lowest unit of Early Paleozoic age is the Tarutao Group, named from its type locality of the island “Ko Tarutao” in Satun Province. Notwithstanding good exposures in the coastal headlands of the island, it is not possible to measure a continuous section and there are added structural complications. Estimates of the thickness of this group have therefore varied widely. Lee (1983) also considered it to have an aggregate he divided it into three as follows: Upper unit is fining – upward sequence of very fine – grained sandstone, siltstone and tuffaceous mudstone with minor limestone intercalations. Middle unit is cross – bedded, fine to coarse – grained sandstone, conglomerate with rare acid tuff and heavy – mineral bands. Lower unit is coarsening upward succession of alternating graded siltstones, mudstones and argillaceous sandstones.

Ordovician: The Thung Song is a thick sequence of Ordovician limestone, dolomite and calcareous shale. It is a dark – grey argillaceous, somewhat siliceous limestone with conspicuous and characteristic dark banding. Wongwanich *et al*. (2002) recognize seven units on Ko Tarutao are follows: Malaka Formation is laminated of muddy limestone and dolomitic limestone in the lower unit is volcanic sandstone. Talo Dang Formation is pink to grey nodular limestone and grey to red calcareous shale. La Nga Formation is thick grey limestone and laminated dolomite. Pa Nan Formation is branching digitate stromatolite. Lae Tong Formation is laminated muddy limestone, red – greenish grey shale and lower unit is nodule limestone. Rung Nok Formation is white limestone. Pa Kae Formation is red limestone and red shale.

Silurian – Devonian: Thong Pha Phum group is black shale, chert, sandstone and limestone At least three lithostratigraphic units are follows: Wang Tong Formation is shale, chert and greenish grey sandstone. Kuan Tung Formation is grey limestone and stromatolite limestone. Pa Samed Formation is black shale, brown – red sandstone and grey – black laminated shale.

3) Upper Paleozoic

Carboniferous: The rock unit is shale, sandstone, chert, argillite, and siltstone. Kuan Klang Formation is composed chiefly of grey and reddish shale with intercalations of arkosic and quartzose sandstone, siltstone and chert. Yaha formation is mainly siliciclastic succession of shale, medium – to – coarse – grained sandstone, siliceous shale, chert and conglomerate.

Carboniferous – Permian: The Kaeng Krachan Group is widely distribution in Peninsular Thailand, particularly in the Upper Peninsula. The group, composed of various siliciclastic rocks, is defined here as a lithostratigraphic unit beneath the Ratburi Limestone and above the potential Mississippian formations discussed above. It is characterized by common intervals of diamictite, pebbly mudstone and mudstone with dropstone. This stratigraphic unit was originally introduced as the Kaeng Krachan Formation by Javanaphet (1969) for a thick succession of poorly bedded greywacke, mudstone, siltstone and minor limestone. In addition to these lithofacies, well – bedded black and grey shale and granite are also characteristic. This formation as mainly distributed in Peninsular Thailand.

Permian: The Ratburi limestone was originally introduced by Brown *et al*. (1951) for thick and prominent carbonates present over much of Thailand, which they considered to be Carboniferous – Permian in age. These formations are mostly massive to bedded carbonates mainly limestone with occasional chert nodules, often recrystallized and locally dolomitized with minor sandstone and shale intercalations.

4) Mesozoic

Triassic: Triassic unit covering Songkhla province consists of conglomerate, red – brown sandstone, fine – sandstone interbedded siltstone, shale and black – grey limestone.

Jurassic – Cretaceous: Rock unit covering Surat Thani, Songkhla, Krabi and Trang province consists of red – brown sandstone, siltstone, shale, conglomerate, interbedded limestone and tuff.

5) Cenozoic

Tertiary: The complete stratigraphy of Tertiary basins in southern Thailand is Krabi basin. This can be subdivided into six formations. These formations are from top to bottom; Huai Khram formation consists of brownish to grey clays, claystone, sandstone and gravel. Tha Nun formation consists og grey to brownish grey claystone, sandstone, and siltstone. It has thin coals seams in the northern part of the basin and grey to reddish brown claystone with fine – to coarse – grained sandstone in the southern part of the basin. Khuan Muang formation consists of grey to greenish grey, fossiliferous claystone, slightly silty and sandstone interbeds. Khlong Sait formation consists of grey claystone, fine – grained sandstone and fossiliferous limestone. Pakasai formation consists of grey to greenish grey claystone, limestone, and shale that is, in part, calcareous and fossiliferous. Sandstone and siltstone occur as interbeds in the western part of Krabi basin. Bang Pu Dum formation consists of greenish grey to grey claystone, sandstone, limestone, and carbonaceous claystone with several thin coal seams. It gradually changes to reddish brown and grey claystone, siltstone, and sandstone in its lower part.

Quaternary: The southern peninsula consists of the mountain range in the middle part and slope downward to coastal plain on both sides of the peninsula. Coast is stretching along the Gulf of Thailand and Andaman Sea with the distance of 1,700 km and 937 km respectively. The geomorphic features along both coastal plains are different and affected to the variety of Quaternary deposits in Southern Region.

The Gulf of Thailand coast can be classified into 4 main geomorphic features, series of coastal barriers in Songkhla province, (1) broad tidal flat plain and (2) beach ridges in Nakhon Si Thammarat province, (3) delta plain in Surat Thani province and (4) narrow bay alternating cliff in Surat Thani province. The depositional environments of Quaternary sediments along the east coast are related to the source rocks, geomorphic landscapes and climate in each time period. Generally, long period of weathering and erosion alternating with fluvial transportation during the Tertiary to early Quaternary time caused the deposition of colluvial and alluvial sediments of Pleistocene age. The short period of Late Pleistocene marine transgression was also recorded as the shelly bed (30,950 ± 620 yr. B. P.) found under the stiff clay along the coast of Songkhla. The global climate warm during the Late Pleistocene to Early Holocene caused the sea invasion into the upland areas as far as 40 km In Nakhon Si Thammarat province with elevation 4 to 5 meters above present mean sea level. After Middle Holocene, the sea started to retreat backward and the coastal plain deposited as the regressive sequence over transgressive sequences.

The Andaman Sea coast lies along the western part of Peninsular Thailand in Krabi, Trang, and Satun province. Two main faults, Ranong and Khlong Marui, caused the development of geomorphic features in this coastal area as short and narrow beach barriers between cliff coast and vast mangrove swamp in limestone knolls. Two main Quaternary sequences were classified based on geomorphology, lithology, and paleontology evidences. The Pleistocene sequence occurs along the mountain foot as undulating terrain and the cliff coast. It composes of residual deposits and colluvial deposits. The complete succession of weathered rock toward saprolite and laterite can be observed over the Andaman Sea coast. The colluvial deposits cover upland areas attached the coastal plain and consist of coarse gravel of parent rock. The dating of peat and wood fragments in stiff clay unit at Phuket mine revealed the age of 31,050 ± 280 yr. B. P. (Kruse, 1983) and from the peat sample at Phang Nga as 30,430 ± 1,160 yr. B. P. (Sinsakul and Jongkarnjanasoontorn, 1984). This stiff clay unit is commonly found widespread over the Andaman Sea coastal area and usually underlay the Holocene sequence. The Holocene sequences are mainly marine origin and were classified into two main groups according to their morphologic evidences as tidal flat and beach sand. By the result of C14 dating of peat and shell fragments in tidal flat sediments, the marine clay deposited since 9,000 yr. B. P. to present day depends upon the depth of sedimentary sequence. The beach sand group also developed from 6,000 yr. B. P. till the last hundred years and usually covers the tidal flat sediments.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Works

2.1.1 Quaternary Geology and Coastal Change

Sinsakul (1992) suggested that the coastal area of Thailand consists of two main regions, the Andaman sea coast on the west and the Gulf of Thailand coast on the east. The coastal landform was related to sea level change particularly that occurring during the Quaternary period.

The Quaternary geology of coastal areas was discussed by Dheeradilok (1995), Sinsakul (2000) and Sinsakul *et al*. (2002). The Quaternary is a period of Cenozoic Era and can be divided into the Pleistocene and the Holocene Epochs. The Quaternary sediments are mainly semi – consolidated to unconsolidated. The classification of Quaternary sediments in Thailand was based on geomorphology, lithology, depositional environments and fossils. Pleistocene deposits were related to neo – tectonics, changing of alluvial and fluvial systems, weathering in place of the bed rocks, and sea level change. Holocene deposits were concerned mainly with the climatic change and the marine sediments related to the fluctuation of sea level. The southern peninsula consists of the Pleistocene sequence which occurs along the mountain foot as undulating terrain and the cliff coast and the Holocene sequence which is classified into two main groups according to their morphologic evidences as intertidal flat and beach sand.

Nutalaya (1996) gave an overview of the coastal erosion problem in coastal area of the Gulf of Thailand. The past two decades the coastal areas surrounding the Gulf of Thailand had been progressively eroded. The coastal areas which used to be villages, resorts, salt pans, shrimp ponds, and mangrove, were now under the sea water. The intensity and rate of coastal erosion were continuing without any sign of slowing down.

The technical reports of Department of Mineral Resources (DMR) by Sinsakul et al. (2001 and 2002) included the study of the changing coastal areas of the Andaman Sea coast and the Gulf of Thailand coast. The evidence of coastal change can be classified into erosion, deposition and stable coast. The detailed study focuses on the erosional coast which can be classified into severe erosion with erosion rates of more than 5 meters per year and moderate erosion with rates between 1 – 5 meters per year. Rate of erosion is based on the evidence of physical change, as well as on the economic and social repercussions of each coastal zone. In the Andaman Sea coast, the stable coast comprised 84.2% and 3.7% can be classified as depositional coast. Moderate erosion occurred at 9.65% of the coast while only 2.45% were severely eroded. In the Gulf of Thailand coast, the depositional coast comprised 7.49%. Moderate erosion occurred at 17.74% of the coast while only 10.64% were severely eroded.

Wichaimekphat (2006) and Jarungrattanapong (2008) studied the coastal erosion in Bang Khun Thian district of Bangkok that had been suffered from severe erosion with the rates of 1.2 – 4.6 meters per year. Thampanya *et al*. (2006) studied the coastal erosion and mangrove progradation of southern Thailand. The erosion was significantly higher along the eastern coast than the western coast. Eroded areas were found to increase with increased area of shrimp farms, increased fetch to the prevailing monsoon, and construction of dams to reduce riverine inputs.

2.1.2 Remote Sensing and Geographic Information Systems (GIS)

There were many attempts to apply and utilize remote sensing to detect the coastal change areas as described below.

The shoreline evolution was the most concern of the coastal engineers and managers (Thao et al.,2008 and Prabaharan et al.,2010). There are several approaches to calculate the rates of shoreline change such as numerical models and remote sensing technique. By integrating modern techniques of remote sensing and GIS, the rates of shoreline change would be easily and quickly determined for a regional area.

Frihy et al. (1998) studied the shoreline change in Nile delta which had been analyzed by comparisons of Landsat satellite image data acquired in 1978, 1983, 1990 and 1995. The images were utilized together with a series of topographic maps dated 1909, 1922, 1944 and 1955 to cover 86 years monitoring period. The shoreline change in this study included areas of shoreline erosion and accretion. White (1999) described the coastline movement due to erosion and deposition which was a major concern for coastal zone management. The very dynamic coastlines of the Nile Delta coast pose considerable hazards to human use and development. Rapid and replicable techniques are required to update coastline maps of these areas and to monitor rates of movement. The synoptic capability of Landsat Thematic Mapper imagery enables monitoring of large sections of coastline at relatively coarse (30 meters) spatial resolution. By comparing positions of the Nile Delta coast in 1984, 1987 and 1990/1991, mapped using a region – growing image segmentation technique, areas of rapid change can be identified and targeted for more detailed monitoring in the field, or using higher resolution images. Rates of erosion and deposition can be estimated crudely, and areas where change appears to be accelerating can also be identified. Zakariya et al. (2006) used the satellite imagery on standardizing and processing technique for change detection analysis to improve results accuracy. Base on the result, shoreline and sandy area in the study area were easily detected using Landsat imagery. The delineation technique process was compatible and easy to use for fast shoreline and sandy area detection at coastal environment. The ortho aerial photo and hydrographic survey datum were utilized to quantitatively analyze coastal erosion and sediment patterns by Yang et al. (2005). The methods of ortho aerial photo and the marine observation datum were the effective ways of change detection in erosion, sediment, and artificial reclamation of the coastline for a long time. Di et al. (2003) used the new generation of high – resolution and multispectral IKONOS and QuickBird imagery for digital stereo mapping. Their high resolution and short revisit rate (approximately 3 days) make the images very valuable for shoreline mapping and coastal change detection.

Marfai et al. (2008) used the multi – years shoreline mapping for the coastal monitoring and assessment. The shoreline dynamic used multi – sources spatial data. The segment data had been obtained by visual delineation of the topographic maps, IKONOS, Landsat MSS and Landsat ETM. Asmar et al. (2011)

utilized a set of satellite images from the Landsat (MSS), Landsat (TM) and SPOT to estimate the spatial – temporal changes that occurred in the coastal zone.

Marghany (1999) predicted the coastal erosion by using Polarised TOPSAR and ERS – I. The simulations of quasi – linear model and radon transform were used to model the shoreline change. The rate of shoreline change was modeled with a different date. The vectors of shoreline were used to find also the rate of shoreline change. The different methods used to detect shoreline change were compared by using a statistical model. The statistical model shows that radon transfer model had a good correlation with wave spectra model and vectors of shoreline rate change. The coastal erosion occurred due to the change of wave spectra refraction pattern. The radon transform could be used as new method to detect a shoreline change from remotely sensed data. *Elkoushy* et al. *(2004)* applied the aerial images to shoreline changes. The data obtained from aerial images could be integrated into GIS to study the changes occurs in the shoreline for a wide area during different years which can help us to predict the shoreline changes. Aerial images could be a faster and more efficient monitoring system, with high accuracy when using all available techniques for tracing the shoreline such as least squares matching, coordinates transformation, minimum GPS control points and GIS. Maiti et al. (2009) studied the shoreline change analysis and prediction which were conventionally performed by field and aerial surveys. Multi – date satellite images had been used to demarcate shoreline positions, from which shoreline change rates had been estimated using linear regression. Shoreline interpretation error, uncertainty in shoreline change rate, and cross – validation of the calculated past shorelines have been performed using the statistical method.

Zhang et al. (2009) and Ho et al. (2010) studied the methodology for classification of NDWI. The normalized difference water index (NDWI) has been used to delineate surface water features. The evaluation of the NDWI for determining the best performing index and establish appropriate thresholds for clearly identifying water features. The spectral data obtained from a spectral library to simulate the satellite sensors Landsat ETM, SPOT, ASTER, and MODIS are used to calculate to the simulated NDWI in different forms. The result found that the NDWI calculated from (green – SWIR) / (green + SWIR), where SWIR is the shorter wavelength region (1.2 to 1.8 mm), has the most stable threshold. They recommended this NDWI be employed for mapping water, but adjustment of the threshold based on actual situations is necessary.

Safavian et al. (1991), Pal et al. (2001), Ghose et al. (2010) and Pooja et al. (2011) employed the decision tree classification of remote sensing satellite data for delineation of coastline. A decision tree classification had a simple form which can be compactly stored and efficiently classifies new data. Decision tree classification can perform automatic feature selection and complexity reduction, which the tree structure gives easily understandable and interpretable information regarding the predictive or generalization ability of the data.

2.2 Coastal Landforms

A shoreline is the demarcation between subaerial and subaqueous landforms. A coastline specifies an oceanic shoreline. In the more general sense, a coast refers to a zone of indefinite width on both sides of the coastline, so we freely speak of coastal shipping, coastal highways, etc. By that usage, coastal landforms are those that are in any way influenced or controlled by proximity to the sea, such as the inland extent of salt spray that affects plants or soil. Beyond that general statement, coastal landforms are difficult to classify. Many coasts are simply drowned portions of a subaerial landscape or exposed portions of the sea floor, on which the position of the coastline is the random result of land uplift or subsidence or of a rise or fall of sea level (Bloom, 1998).

Although hard to define and transient in time and space, a coastline has profound geologic implications. Above sea level, all land must be eroded by rain, rivers, wind, and glaciers. The coast marks the line at which the erosion products are dropped and become new marine sedimentary deposits. Thus the coastline denotes the transition from net erosion to net deposition on our planet.

2.2.1 Coastal Environments

Waves: Waves are undulations formed by wind blowing over a water surface. They are caused by turbulence in air – flow generating pressure variations on the water. Once formed, waves help to disturb the airflow and are partly self – sustaining. Energy is transferred from the wind to the water within the wave – generation area. The amount of energy transfer depends upon the wind speed, the wind duration (how long the wind blows), and the fetch (the extent of water over which the wind blows). Sea waves are formed by the wind within the generation area. They often have short crests and steep cross – sections, and are irregular. In mid – ocean, prolonged strong winds associated with severe storms and blowing over hundreds of kilometers produce waves more than 20 m high that travel up to 80 km / hr. On passing out of the generation area, sea waves become swell waves (or simply swell) and they are more regular with longer periods and longer crests. They may travel thousands of kilometers across oceans (Huggett, 2007).

Waves formed in water deep enough for free orbital motion to occur are called waves of oscillation. The motion is called 'free orbital' because the chief movement of the water is roughly circular in the direction of flow, backwards in the trough, and downwards on the back (Figure 2.1). Water moved slowly in the direction of wave propagation because water moves faster on the crest than in the troughs. Oscillatory waves form wave trains. Solitary waves or waves of translation, in contrast, involve water moving in the direction of propagation without any compensatory backward motion. They are single, independent units and not associated with wave trains. They lack the distinct crests and troughs of oscillatory waves and appear as weals separated by almost flat water surfaces and are effective transporters and eroders of sediments and rock. They are often generated by the breaking of oscillatory waves.

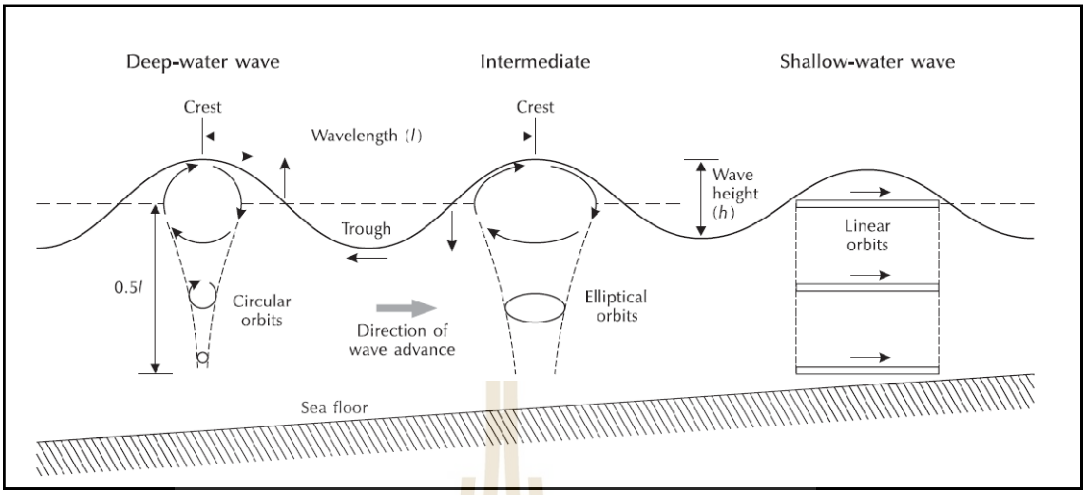


Figure 2.1 Term associated with waves, including the orbital motion of waves in deep, intermediate, and shallow water (Huggett, 2007).

Once waves approaching a coastline 'feel bottom', they slow down. The waves crowd together, and their fronts steepen. Waves refraction occurs because the inshore part of a wave crest moves more slowly than the offshore part, owing to the shallow water depth, and the offshore part swings forwards and the wave crests tent to run parallel to the depth contours

Nearshore Currents: Currents are created in the nearshore zones that have a different origin from ocean currents, tidal currents, and wind – induced currents (Huggett, 2007). Nearshore currents are produced by waves. They include longshore currents, rip currents, and offshore currents (Figure 2.2). Longshore or littoral currents are created when waves approach a coastline obliquely. They dominate the surf zone and travel parallel to the coast. Rip currents, or rips, are fed by longshore currents and develop at more or less regular intervals perpendicularly to the beach and flow through the breaker zone. They are strong currents and dangerous to swimmers. Onshore currents are slower and develop between rip currents. Even where waves approach a coastline head on, a nearshore circulation of longshore currents, rip currents, and onshore currents may evolve.

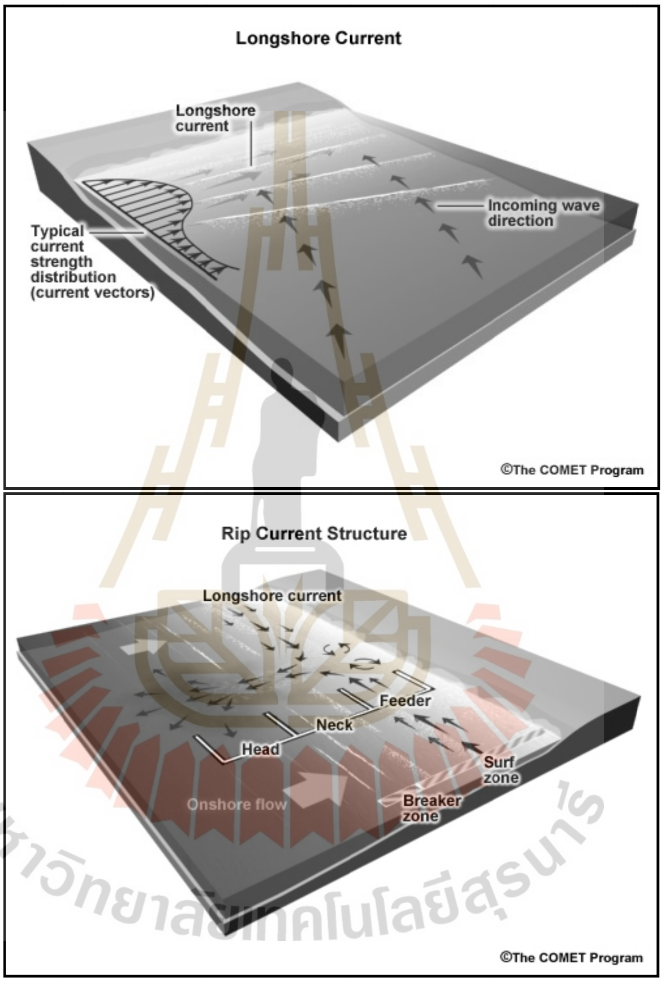


Figure 2.2 Circulation of longshore current and rip current.

Tides: Tides are the movement of water bodies set up by the gravitational interaction between celestial bodies, mainly the Earth, the Moon, and the Sun (Huggett, 2007). They cause changes of water levels along coasts. In most places, there are semi – diurnal tides – two highs and two lows in a day. Spring tides, which are higher than normal high tides, occur every 14 – 75 days when the Moon and the Sun are in alignment. Neap tides, which are lower than normal low tides, alternate with spring tides and occur when the Sun and the Moon are positioned at an angle of 90° with respect to the Earth. The form of the 'tidal wave' depends upon several factors, including the size and shape of the sea or ocean basin, the shape of the shoreline, and the weather. Much of the coastline around the Pacific Ocean has mixed tides, with highs and lows of differing magnitude in each 24 – hour period.

Tidal ranges have a greater impact on coastal processes than tidal types. Three tidal ranges are distinguished – microtidal (less than 2 m), mesotidal (2 to 4 m), and macrotidal (more than 4 m) – corresponding to small, medium, and large tidal ranges. A large tidal range tends to produce a broad intertidal zone, so waves must cross a wide and shallow shore zone before breaking against the high – tide line. This saps some of the waves' energy and favours the formation of salt marshes and tidal flats. The greatest tidal ranges occur where the shape of the coast and the submarine topography effect an oscillation of water in phase with the tidal period. Small tidal ranges encourage a more unremitting breaking of waves along the same piece of shoreline, which deters the formation of coastal wetlands.

Tides also produce tidal currents that run along the shoreline. They transport and erode sediment where they are strong, as in estuaries. Currents associated with rising or flood tides and falling or ebb tides often move in opposite directions.

2.2.2 Coastal Erosional Landforms

Landforms of coastal erosion include cliffs, wave-cut platforms, arches, stacks, headlands and caves (Figure 2.3). The existence of many of these features depends upon the maintenance of a vertical cliff-face through an on – going cycle of undercutting, collapse and retreat. When waves break at the foot of a rock face, a wave-cut notch is created by marine erosion processes. Over time, a section of rock is removed from the bottom of the cliff face, leading ultimately to the collapse of the un-supported section above. Every time this process is repeated, a new near – vertical cliff-face is created.

Without marine erosion operating in this way, sub-aerial processes (normal atmospheric weathering processes such as carbonation or hydrolysis) would degrade the cliff face, creating a gentle slope where the upper element has been worn away by weathering while fallen material collects at the bottom of the cliff. Vegetation can colonies such slopes over time, leading to greater stability. Wherever land has risen from the sea in the past as a result of isostatic processes (when land subsides, rises or tilts), degraded cliffs can often be seen that are no longer reached by the sea. Instead of boasting a dramatic near – vertical profile, gentle vegetated slopes are apparent on account of marine erosion no longer attacking and undermining the landform

Headlands: A headland is a point of land, usually high and often with a sheer drop that extends out into a body of water. The word is often used as a synonym for promontory. A headland is often referred to as simply a head, either in context or in names such as Beachy Head.

Cliffs: Cliff is a significant vertical, or near vertical, rock exposure. Cliffs are formed as erosion landforms due to the processes of erosion and weathering that produce them. Cliffs are common on coasts, in mountainous areas, escarpments and along rivers. Cliffs are usually formed by rock that is resistant to erosion and weathering. Most cliffs have some form of scree slope at their base. In arid areas or under high cliffs, these are generally exposed jumbles of fallen rock. In areas of higher moisture, a soil slope may obscure the talus. Many cliffs also feature tributary waterfalls or rock shelters. Sometimes a cliff peters out at the end of a ridge, with tea tables or other types of rock columns remaining.

Caves: Sea caves are found along coasts around the world. A special case is littoral caves, which are formed by wave action in zones of weakness in sea cliffs. Often these weaknesses are faults, but they may also be dykes or bedding – plane contacts. Some wave – cut caves are now above sea level because of later uplift. A sea cave, also known as a littoral cave, is a type of cave formed primarily by the wave action of the sea. The primary process involved is erosion. Sea caves are found throughout the world, actively forming along present coastlines and as relict sea caves on former coastlines.

Arches: A natural arch or natural bridge is a natural geological formation where a rock arch forms, with an opening underneath. Most natural arches form as a narrow ridge, walled by cliffs, become narrower from erosion, with a softer rock stratum under the cliff-forming stratum gradually eroding out until the rock shelters thus formed meet underneath the ridge, thus forming the arch. Natural arches commonly form where cliffs are subject to erosion from the sea, the processes "find" weaknesses in rocks and work on them, making them larger until they break through.

Notches: Cliff – base notches are sure signs of cliff erosion. Shallow notches are sometimes called nips. The rate at which notches grow depends upon the strength of the rocks in which the cliff is formed, the energy of the waves arriving at the cliff – base, and the amount of abrasive material churned up at the cliff – beach junction.

Stacks: A stack is a geological landform consisting of a steep and often vertical column or columns of rock in the sea near a coast, isolated by erosion. Stacks are formed through processes of coastal geomorphology, which are entirely natural. Time, wind and water are the only factors involved in the formation of a stack. They are formed when part of a headland is eroded by hydraulic action, which is the force of the sea or water crashing against the rock. The force of the water weakens cracks in the headland, causing them to later collapse, forming free – standing stacks and even a small island. Without the constant presence of water, stacks also form when a arch collapses under gravity, due to sub – aerial processes like wind erosion.

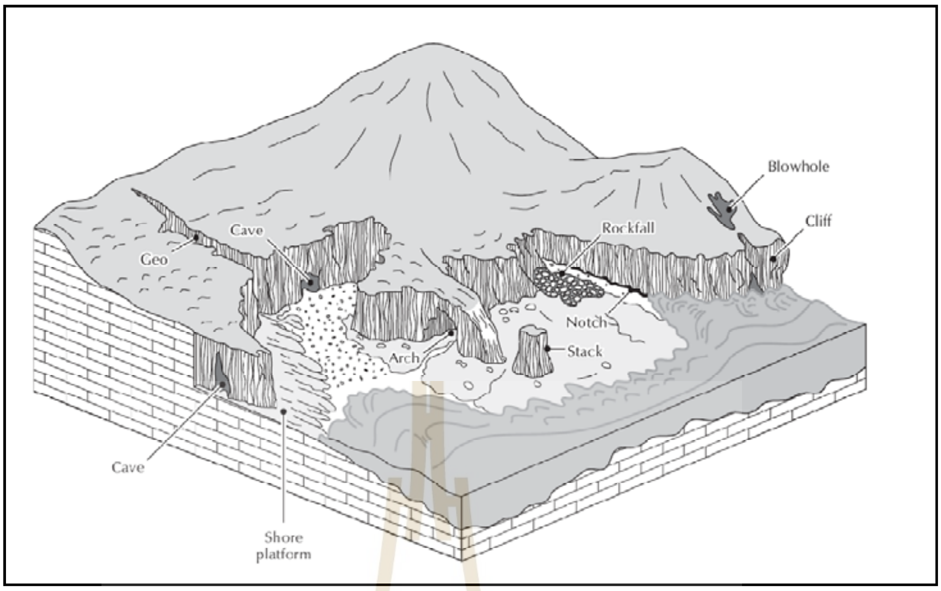


Figure 2.3 Erosional features of rocky coast (Huggett, 2007).

2.2.3 Coastal Depositional Landforms

Coastal deposition is the laying down of material on the coast by the sea. It occurs when waves lose energy or when large inputs of sediment are made into the coastal system – perhaps due to the arrival of fluvial sediment at a river estuary. Wave refraction in bays also encourages deposition due to the dispersal of wave energy. Lower – frequency constructive waves often contribute to deposition due to their strong swash, moving beach material inland.

In addition to beaches, a range of unique depositional landforms exist, including the bar, spit, tombolo and cuspate foreland (Figure 2.4). The formation of these landforms additionally depends upon the process of longshore drift. This occurs when waves approach a coast – line at an angle, due to the dominant wind. There is thus a sideways component to the swash which helps move beach material diagonally up the beach (it travels laterally as well as inshore). Depositional landforms can be highly vulnerable to erosion during extreme storm events unless vegetation colonization has taken place. Plant roots can help anchor sediments, making them more resistant to the action of destructive waves.

Beaches: A beach is a geological landform along the shoreline of an ocean, sea, lake or river. It usually consists of loose particles which are often composed of rock, such as sand, gravel, shingle, pebbles or cobblestones. The particles comprising the beach are occasionally biological in origin, such as mollusc shells or coralline algae. Beaches typically occur in areas along the coast where wave or current action deposits and reworks sediments.

Spits: A spit or sandspit is a deposition landform found off coasts. At one end, spits connect to land, and extend into the sea. A spit is a type of bar or beach that develops where a re – entrant occurs, such as at cove's headlands, by the process of longshore drift. Longshore drift (also called littoral drift) occurs due to waves meeting the beach at an oblique angle, and backwashing perpendicular to the shore, moving sediment down the beach in a zigzag pattern. Longshore drifting is complemented by longshore currents, which transport sediment through the water alongside the beach. These currents are set in motion by the same oblique angle of entering waves that causes littoral drift and transport sediment in a similar process.

Barriers: Barrier islands are elongated offshore ridges of sand paralleling the mainland coast and separated for almost their entire length by lagoon, swamps, or other shallow – water bodies, which are connected to the sea by channels or tidal inlets between islands. They are also called barrier beaches, barrier bars, and offshore bars. Sections of long barrier – island chains may be large spits or barrier beaches still attached to land at one end. As to their formation, some barriers are sections of long spits that have become detached, while some may have been formed by the rising sea levels over the last 10,000 years and perhaps have grown on former dunes, storm ridges, and berms, with lagoon forming as the land behind the old beaches was flooded. Barrier beaches may also have formed by the accumulation of sediment carried landwards by wave action as sea level rose.

Tombolos: Tombolos are wave – built ridges of beach material connecting islands to the mainland or islands to islands. They come in single and double varieties. Tombolos tend to grow in the lee of islands, where a protection is afforded from strong wave action and where waves are refracted and convergent. Y – shaped tombolos develop where comet – tail spits merge with cuspate forms projecting from the mainland or where a cuspate barrier is extended landwards or seawards. A tombolino tie – bar is a tombolo that is partly or completely submerged by the sea at high tide.

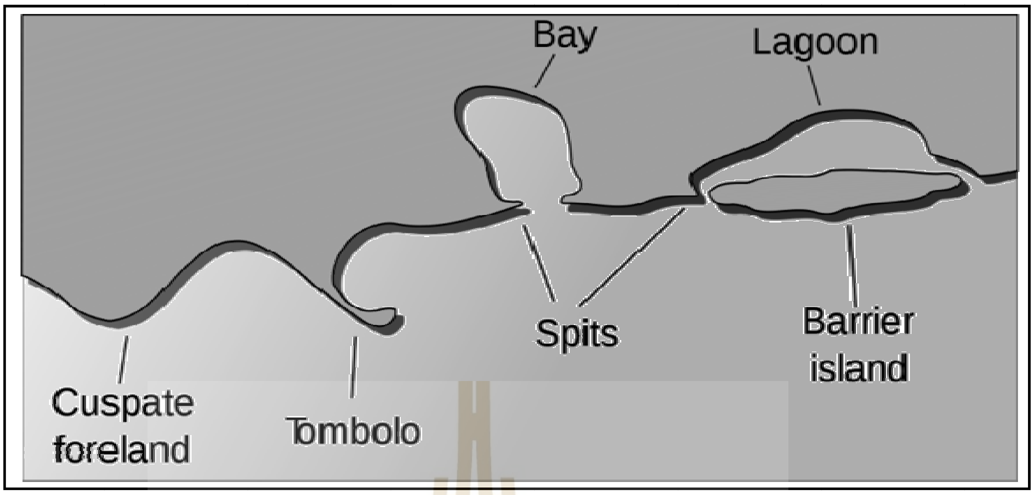


Figure 2.4 Depositional landforms.

Coastal Sand Dunes: Coastal dunes are heaps of windblown sediment deposited at the edge of large lakes and seas. With few a exceptions, they are made from sediment blow off a beach to accumulate in areas sheltered from the action of waves and currents. Small, crescentic dune fields often form at the back of bays enclosed by rocky headlands, while larger prograding dune fields from on straight, sandy coasts that are exposed to prevailing and dominant onshore winds. They shield the land from extreme waves and tides and are stores of sediment that may replenish beaches during and after storms. Coastal dune are mainly composed of medium – size to fine quartz grains that are well to very well sorted, but calcium carbonate is common in warm tropical and Mediterranean regions.

Estuaries: Estuaries are tidal inlets, often long and narrow inlets, which stretch across a coastal alluvial plain or run inwards along a river to the highest point reached by the tide. They are partially enclosed but connected to the open sea. They are transition zones between rivers and the sea in which fresh river water mixes with salty ocean water. Early in their evolution, their shape is determined by coastal topography, but this changes fairly rapidly as sediment erosion and deposition reach a steady state. Many are young features formed in valleys that were carved out during the last glacial stage and then drowned by rising sea levels during the Holocene epoch.

Tidal Flats: Tidal flats are banks of mud or sand that are exposed at low tide. They are not actually flat but slope very gently towards the sea from the high – tide level down to a little below the low – tide level. Three basic units may be identified in tidal flats: the high – tide flat (a gently sloping surface that is partly submerged at high tide); the intertidal slope (a steeper but still gently incline zone lying between the high – tide flat and the lower tidal limit); and the subtidal slope, which is submerged even at low tide (Figure 2.5).

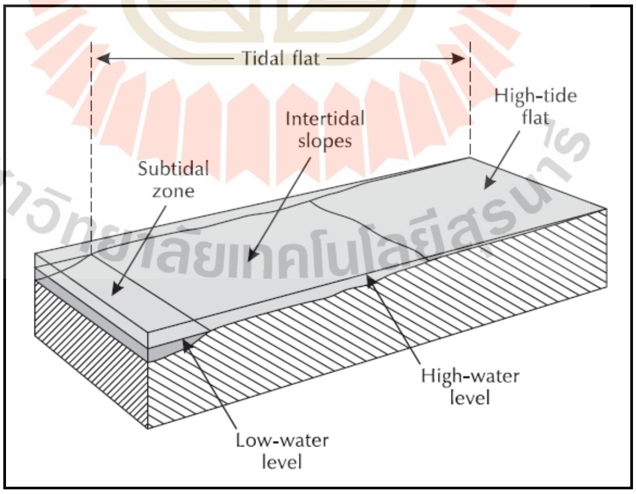


Figure 2.5 Tidal flats and their morphological units based on low – tide and high – tide positions (Huggett, 2007).

Marshes: Marshes are widespread in temperate regions, but are not uncommon in the tropics. They start to form when tidal flats are high enough to permit colonization by salt – tolerant terrestrial plants. Depending on their degree of exposure, salt marshes stretch from around the mean high – water, neap – tide level to a point between the mean and extreme high – water, spring – tide levels. Their seaward edge abuts bare intertidal flats, and their landward edge sits where salt – tolerant plants fail to compete with terrestrial plants. Salt marshes sediments are typically heavy or sandy clay, silty sand, or silty peat. Many salt marshes contain numerous shallow depressions, or pans, that are devoid of vegetation and fill with water at high spring tides.

Mangroves: Mangrove is a general term for a variety of mainly tropical and subtropical salt – tolerant trees and shrubs inhabiting low inter – tidal areas. Mangals are communities of mangroves – shrubs and long – lived trees and with associated lianas, palms, and ferns – that colonize tidal flats in the tropics, and occur in river – dominated, tide – dominated, and wave – dominated coastal environments. They specifically favor tidal shorelines with low wave energy, and in particular brackish waters of estuaries and deltas. Some mangrove species are tolerant of more frequent flooding than salt marsh species, and so Mangals extend from around the high spring – tide level to a little above mean sea level. They often contain lagoon and pools, but not the pans of salt marshes. Like salt marshes, Mangals have creek systems, although their banks are often formed of tree roots.

2.3 The Classification of Coastal Change

Coastal change is diverse and complex natural processes which continually change coasts physically, chemically, and biologically, at scales that range from microscopic (grains of sand) to global (changes in sea level). Regional and local characteristics of coasts control the differing interactions and relative importance of these natural processes. Human activity adds yet another dimension to coastal change by modifying and disturbing, both directly and indirectly, the coastal environments and the natural processes. Earth-science research on coastal dynamics can quantify these changes and improve our ability to predict coastal responses to human actions. The evidence of coastal change can be classified into coastal erosion, coastal deposition and stable coast (Sinsakul, 2001).

2.3.1 Coastal Erosion

Coastal erosion is the weathering away of land or the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage. Waves generated by storms, wind, or fast moving motor craft cause coastal erosion, which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments. Erosion in one location may result in accretion nearby. The erosion and sediment redistribution may be caused by hydraulic action, abrasion, and corrosion.

Figure 2.6 Coastal erosion in Ban Tha Praya, Pak Panang District, Nakhon Si Thammarat Province (WGS84 UTM 639975E 914064N).

2.3.2 Coastal Deposition

Coastal deposition is the process of material moved up the beach by the swash at an angle which is controlled by the prevailing wind. The backwash then carries materials back down the beach at right angles to the coastline under the influence of gravity. Gradually the material is moved along the coastline, its direction being controlled by the prevailing wind direction. The final process operating at the coast is that of deposition. This is where material that is too heavy to be transported any more is left behind and building up the beach. A number of distinctive features may form due to coastal deposition.

2.3.3 Stable Coast

Stable coastal configurations have been achieved and maintained in areas where there is a balance between sediment supply, subsidence, and coastal processes. However, along stable coasts can be destroyed by intense wave activities generated during storms or by minor transgressions associated with sea level oscillation, when wave can erode the higher portions of the landscape.

2.4 Coastal Change Causes

The coastal change caused by natural processes covers some wide area and taking long time to see the effect. But the effect of those caused by human activities will be obvious soon after, if no good planning to alleviate the change has been applied. The geological factors that cause the coastal change of natural processes are waves, tides, weather, sea – level change and the coastal vegetation. In this study, the cause of human activities is also considered such as sediment starvation, sediment trapping and coastal degradation. The controlling factors are:

2.4.1 Natural Processes

Coastal lands and sediments are constantly in motion. Breaking waves move sand along the coast, eroding sand in one area and depositing it on an adjacent beach. Tidal cycles bring sand onto the beach and carry it back into the surf. Rivers carry sediment to the coast and build deltas into the open water. Storms cause deep erosion in one area and leave thick overwash deposits in another. Plants retain sediment in wetlands and impede movement of coastal dunes. Natural processes that change the water level also affect coastal dynamics. Taken individually, each natural process of coastal transport is complex taken collectively; they create an extraordinarily intricate system that attempts to achieve a dynamic balance.

Waves: Winds create waves that ripple across the surface of lakes and seas until they break on the shallowing bottom and crash into the shore. In many areas, prevailing winds produce waves that consistently approach the coast at oblique angles. Even the slightest angle between the land and the waves will create currents that transport sediment along the shore. These longshore currents are a primary agent of coastal movement they are a major cause of sand migration along barrier and mainland beaches.

Tides: Tides ebb and flood in response to the gravitational attraction of the moon and sun exceptional high and low tides occur each month when the sun and moon are aligned. Tides help determine where the waves break - low on the beach at low tide, high on the beach at high tide - and, therefore, where sand is deposited and removed. Rip tides, or undertow, occur along most beaches and can move significant amounts of sand offshore.

Weather: Storm systems along coasts contain high winds, create large waves, and cause storm surges that raise water levels as much as 7 meters above normal. Although storms are sporadic, they are the primary cause of beach erosion along many coasts. Storms carry sand seaward, forming offshore bars much of this sand migrates landward during calm weather. Some areas are more stormed prone than others.

Sea – Level Changes: Global changes in sea level result from tectonic processes, such as the down – or up – warping of the ocean basins, or from changes in the total volume of water in the oceans. During the last great ice age, which began 36,000 years ago, huge amounts of ocean water were transformed into glaciers, resulting in a 100 - meter drop in the global sea level. We are still emerging from that ice age, and sea level has been rising continuously over the last 20,000 years. During the past century, the rate of sea level rise has averaged 10 - 15 centimeters per century worldwide. The slope of a coast is critical to determining how water-level changes. Steeply sloping coasts experience small shifts in their coastlines as the water level changes. However, small water-level increases can result in significant erosion of bluffs or dunes because wave action along steep coasts is concentrated within a narrow zone.

Coastal Vegetations: Rooted plants flourish along the shores of bays, estuaries, deltas, and other coastal environment that are protected from the full fury of pounding waves. Plants stabilize dunes through root networks. They build and maintain marshes by catching and retaining in their roots the fine sediment carried by the water. Their natural decay cycle further enriches coastal soils and sediment with decomposing plant matter. Differences in weather regimes, tidal depth, and water salinity determine which plant populations will thrive in a given coastal environment.

2.4.2 Human Activities

Human activities add another layer of complexity to the natural processes of coastal lands and materials. These activities may have direct or indirect effects on our changing coasts. They may affect sources of new sediment to the coast and the movement of sediment within the coastal environment they may promote changes in sea level, both local and global.

Sediment Starvation: For some coastal regions, a large part of their sediment budget is supplied by rivers. Dams built for flood control and water catchments along the rivers leading to these coasts inhibit the transport of large-grained sediments. Lacking new material, the sediment - starved coasts are eroded and migrate inland. Attempts to counter sediment starvation along severely eroding coasts have included the artificial replenishment of beach material by placing sand directly onto the beach. Beach nourishment is not a permanent solution and is expensive, but in some regions it can be cost effective. The lack of clean sand suitable for fill often limits beach nourishment programs, but offshore surveys can locate sand bodies for dredging and transport to the beach.

Sediment Trapping: The natural movement of sand is at best a nuisance for owners of beachfront property. When this movement results in a net loss of sand from the beach, the natural process may be considered by owners as a serious threat. To prevent beach loss, groins are often constructed out into the water. These solid structures impede the littoral drift of sand caused by longshore currents. The beach then expands on the updrift side of the groin however the downdrift side of the groin loses sand because of continuing longshore movement. Small groins may have little effect on sediment movement along the entire beach. Seawalls constructed to protect property along retreating beaches often exacerbate beach erosion. They confine the wave energy and intensify the erosion by concentrating the sediment transport processes in an increasingly narrow zone. Eventually, the beach disappears, leaving the seawall directly exposed to the full force of the waves.

Coastal Degradation: Human actions that lead to the destruction of dune grasses and the disturbance of coastal landforms promote increased erosion and movement of beach materials. Off - road vehicles and foot traffic on sand dunes compact sand, destroying plant roots and animal burrows. Other wildlife habitats, such as nesting and feeding areas for shorebirds, are disturbed by human activity. Young birds are especially vulnerable to these disruptions.

2.5 Integrating Remote Sensing and GIS

In recent years, remote sensing has been increasingly recognized as a means of obtaining geo – scientific data for regional and site – specific investigations. Remotely sensed data provides a synoptic perspective view, and covers large areas in a relative short time, which is unachievable with traditional field studies. Remote sensing is an excellent tool for site characterization because it is not limited by extremes in terrain or hazardous conditions, which may be encountered during an on – site appraisal. These are effective for basic and applied research covering a wide range of subject, including mineral exploration, geo – environmental and geo – hazard evaluation.

Geographic Information Systems (GIS) are computerized systems for the storage, retrieval, manipulation, analysis, and display of geographically referenced data. Since they can include physical, biological, cultural, demographic, or economic information, they are valuable tools in natural, social, medical, and engineering sciences as well as in business and planning.

The methods for the integration between remote sensing and GIS is summarized three main ways can be combined to enhance each other: (1) remote sensing is used as a tool for gathering data for use in GIS, (2) GIS data are used as ancillary information to improve the products derived from remote sensing, and (3) remote sensing and GIS are used together for modeling and analysis.

GIS data can be used to enhance the functions of remote sensing image processing at various stages: selection of the area of interest for processing, preprocessing, and image classification. The use of vector polygon to restrict the area of an image to be processed is possible in image processing software. This permits masking operations without raster mask, masking image processing much more efficient because of faster processing times, no need to store intermediate data, and a reduction in data integrity problems. In addition to enhancing the functions of remote sensing image processing at various stages, GIS technology provides a flexible environment for entering, analyzing, managing, and displaying digital data from the various sources necessary for remote sensing applications. Many remote sensing projects need to develop a GIS database to store, organize, and display aerial and ground photographs, satellite images, and field data. Global Positioning Systems (GPS) technology also is essential when remote sensing projects need to collect in situ samples and observations.

The integration models of remote sensing and GIS into two conceptual models: linear and interactive. In the linear model, each of the technology is quite independent of the others. GPS is used to collect ground controls for satellite images. After rectification, satellite images are combined with other data into a GIS database and are used for subsequent analyses and modeling. As seen in Figure 2.11, there is not a direct link between GPS and GIS. The integration between GPS and remote sensing comes in two temporal modes. While the independent mode suggests that GPS data and remotely sensed data are acquired independently, the simultaneous mode is applied when the two kinds of data are collected at the same time, in which the remote sensing platform is equipped with a GPS unit during the flights.

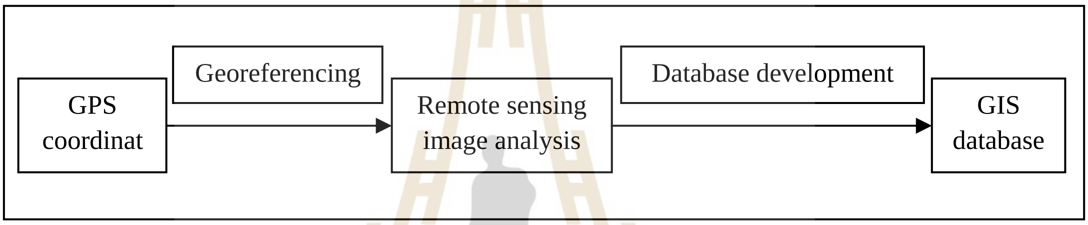


Figure 2.7 The linear model of integration (Qihao, 2010).

In the interactive model, data flow in two directions (Figure. 2.12) instead of one, as seen in the linear model. GPS can feed coordinate data to remote sensing but also can receive data from remote sensing, mainly in the post – image analysis session when classified maps or multitemporal remotely sensed data need to be verified in the field. Similarly, there is two – way flow of data between remote sensing and GIS. The integration of remote sensing with GIS overlay of historic and current maps, whereas integration or classification by using the GIS database.

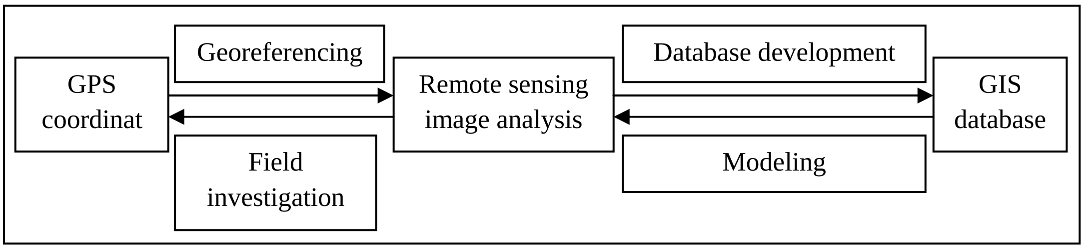


Figure 2.8 The interactive model of integration (Qihao, 2010).

2.6 Change Detection of Remote Sensing

Change detection is an important application of remote sensing technology. It is a technology ascertaining the changes of specific features within a certain time interval (Zhang, 2008). It provides the spatial distribution of features and qualitative and quantitative information of features changes. The quantitative analysis and identifying the characteristics and processes of surface changes is carry through from the different periods of remote sensing data. It involves the type, distribution and quantity of changes, that is the ground surface types, boundary changes and trends before and after the changes.

There are many types of change detection methods of multi – spectral image data. They can be classified as three categories: characteristic analysis of spectral type, vector analysis of spectral changes and time series analysis. The aim of characteristic analysis of spectral type method is to make sure classification and calculation of different phase remote sensing images. The methods are multi – temporal images stacking, algebraic change detection algorithm of image, and change detection of the main components of the image and change detection after classification. The aim of the method of vector analysis of spectral changes is to make sure the strength and direction characteristics of changes based on radicalization changes of images of different time especially analyzing the differences of each band. The aim of the method of time series analysis is to analyze the process and trend of changes of monitoring ground objects based on remote sensing continual observation data.

The method of change detection after classification is the most simple change detection analysis techniques based on the classification. After classification compare method can be used to two or more images after registration, including a classification step and a comparing step. Each image of multi – temporal images is classified separately and then the classification result images are compared. If the corresponding pixels have the same category label, the pixel has not been changed, or else the pixel has been changed.

CHAPTER 3

METHODOLOGY

Various methods for coastal change from satellite imagery have been developed. The integrated remote sensing and GIS is one of the most important data for the coastal change study. It is very useful in detecting and mapping coastline, land use / land cover, topography, geomorphology and geological conditions.

The methods of coastal change detection are described in this chapter. The flow chart of thesis methodology is shown in Figure 3.1.

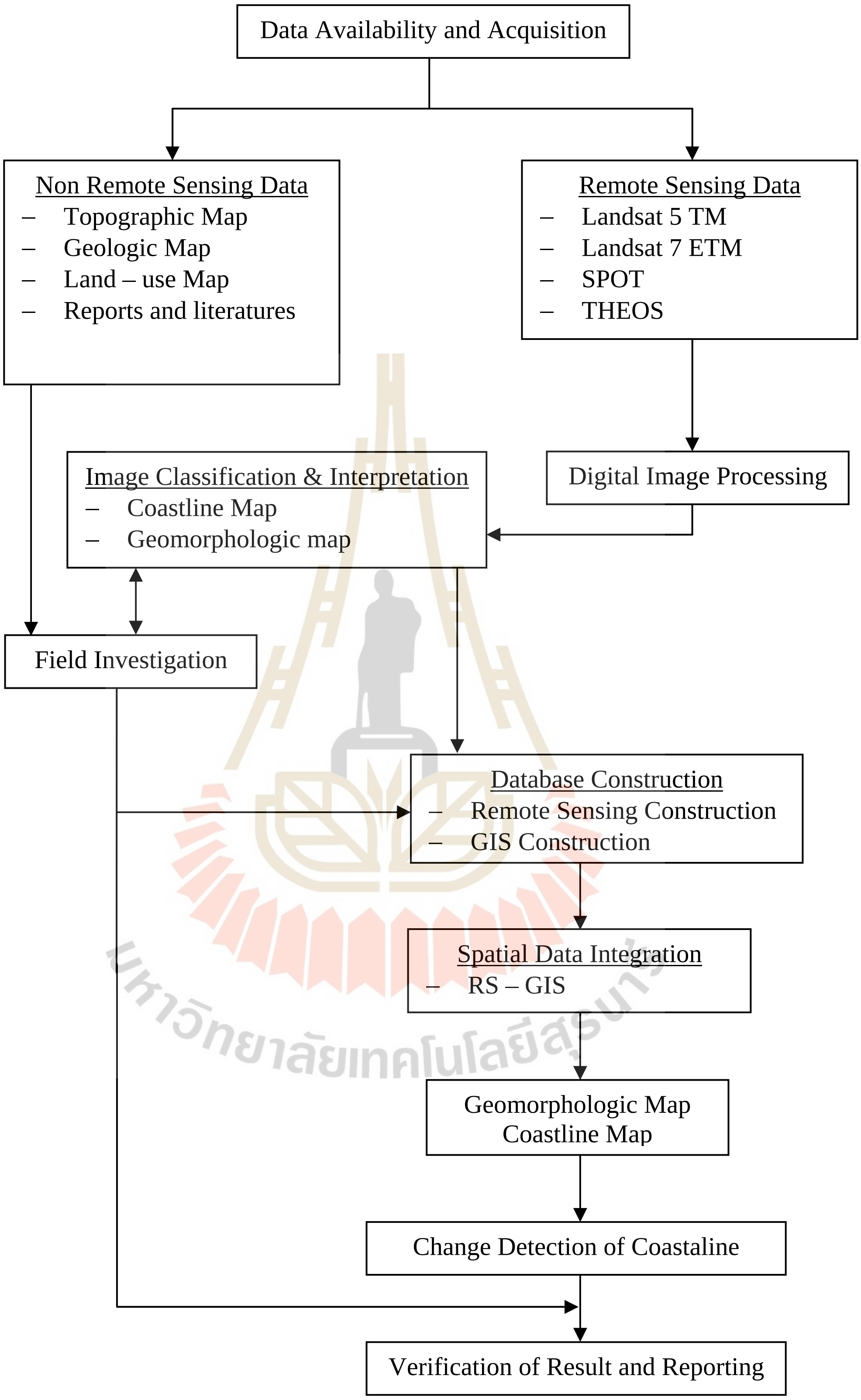


Figure 3.1 Flow chart of thesis methodology.

3.1 Data Acquired and used

The first work of this study includes collecting, storage and selecting all data and information that is available and derived from remote sensing as well as field investigation that are necessary for this study. All kind of data and information will be collected, mapped and reformatted if required and stored in GIS as a database.

According to the data sources, the data acquired and used for the coastal change study can be divided into two groups, remote sensing data and non – remote sensing data.

3.1.1 Remote Sensing Data

Remote sensing is one of the most important data for coastal change study. It is very useful in detecting and mapping coastline, land use / land cover, topography, geomorphology and geological conditions.

There are several types of remote sensing data, which can be integrated for use in the coastal change study. Data of the Landsat TM, Landsat 7, SPOT and THEOS could be acquired for study. Table 3.1 shows an overview of the satellite data used for this study, and Table 3.2 summarizes the major technical parameters of the satellites and the data recording sensors.

3.1.2 Non – Remote Sensing Data

Non – Remote sensing data comprise all maps from available data sources and fieldwork, which are related to the study area such as topographic map, land use / land cover map, geological map, etc. as well as other relevant reports and documents collected from concerning organizations (Table 3.3).

Table 3.1 Overview of satellite data of the study area.

No.	RS-system	Path/Row	Acquisition date
1	Landsat 5 TM	128/54	20 February 1994
2	Landsat 5 TM	128/54	10 August 2004
3	Landsat 5 TM	128/55	1 June 1990
4	Landsat 5 TM	129/54	5 February 1989
5	Landsat 5 TM	129/54	23 September 1994
6	Landsat 5 TM	129/55	5 February 1989
7	Landsat 7 ETM	128/55	6 March 2002
8	Landsat 7 ETM	128/55	14 September 2002
9	Landsat 7 ETM	129/54	22 February 2001
10	Landsat 7 ETM	129/55	22 February 2001
11	SPOT 5	262/331	2 February 2006
12	SPOT 5	263/332	12 March 2006
13	SPOT 5	263/335	12 March 2006
14	SPOT 5	263/336	25 November 2007
15	SPOT 5	264/333	16 March 2007
16	SPOT 5	264/337	28 February 2007
17	THEOS	263/332	31 July 2009
18	THEOS	263/332	21 September 2009
19	THEOS	265/333	10 July 2009

List	Landsat TM	Landsat ETM	SPOT 5	THEOS
Operating Country	USA	USA	France	Thailand
Year of Launch	1984	1999 (failure in 2005)	2002	2004
Orbit (Km)	705	705	832	822
Repetition Cycle (days)	16	16	26	26
Sensor	Scanner (7 bands multispectral)	Scanner (7 bands multispectral, 1 Panchromatic)	Scanner (4 bands multispectral, 1 Panchromatic)	Scanner (4 bands multispectral, 1 Panchromatic)
Spectral Bands (micrometer)	1 (0.45 – 0.52) 2 (0.52 – 0.60) 3 (0.63 – 0.69) 4 (0.76 – 0.90) 5 (1.55 – 1.75) 6 (10.40 – 12.50) 7 (2.08 – 2.35)	1 (0.45 – 0.515) 2 (0.525 – 0.605) 3 (0.63 – 0.69) 4 (0.75 – 0.90) 5 (1.55 – 1.75) 6 (10.40 – 12.50) 7 (2.09 – 2.35) PAN (0.52 – 0.59)	1 (0.50 – 0.59) 2 (0.61 – 0.68) 3 (0.79 – 0.89) 4 (1.58 – 1.75) PAN (0.51 – 0.73)	1 (0.45 – 0.52) 2 (0.53 – 0.60) 3 (0.62 – 0.69) 4 (0.77 – 0.90) PAN (0.45 – 0.90)
Ground Resolution (m)	30×30 120×120 (TIR)	30×30 60×60 (TIR) 15×15 (PAN)	10×10 20×20 (B4) 2.5×2.5 (PAN)	15×15 2×2 (PAN)
Field of view (Km)	185×170	185×170	60×60	90×90

Table 3.2 Technical parameters of the satellite remote sensing systems used.

Table 3.3 Overview of non – remote sensing data types and sources for the study.

Data types	Scale	Original of data format	Sources
Geologic map	1 : 50,000	Shape file of Arc View	Department of Mineral Resources
Land use map	1 : 50,000	Shape file of Arc View	Land Development Department
Topographic map	1 : 50,000	Hard copy	Royal Thai Survey Department

3.2 Methods of Remote Sensing Data Processing and Interpretation

Digital image processing may involve numerous procedures including formatting and correcting the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer. In order to process remote sensing imagery digitally, the data must be recorded and available in a digital form suitable for storage on a computer tape or disk. Obviously, the other requirement for digital image processing is a computer system, sometimes referred to as an image analysis system, with the appropriate hardware and software to process the data. Several commercially available software systems have been developed specifically for remote sensing image processing and analysis. Image processing functions available in image analysis system can be categorized into the following five categories (Figure 3.2):

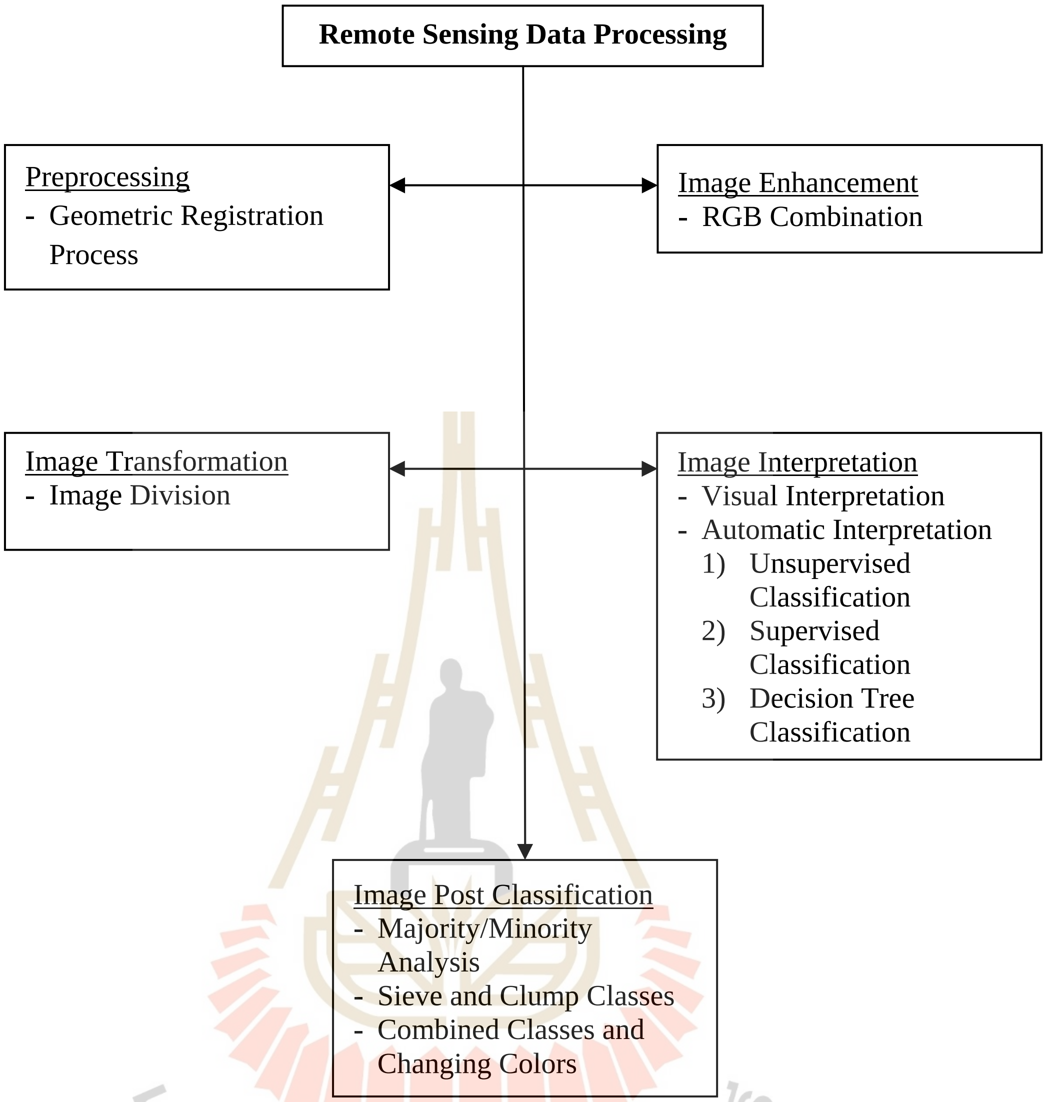
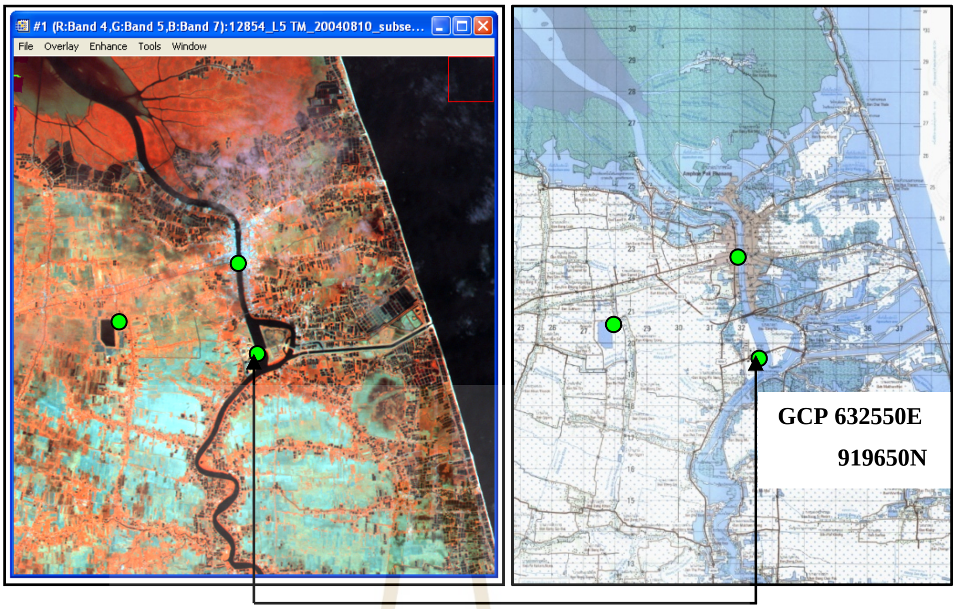


Figure 3.2 Flow chart of remote sensing data processing.

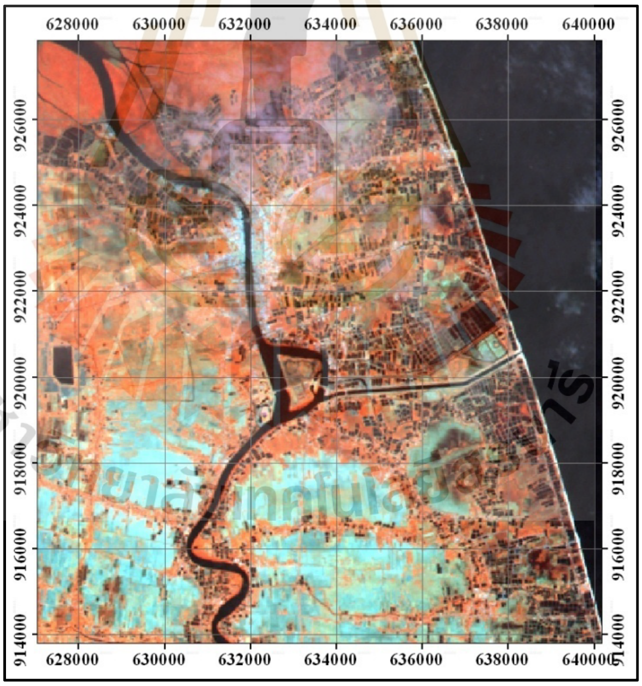
3.2.1 Preprocessing

Preprocessing functions involve those operations that are normally required prior to the main data analysis and extraction of information, and are generally grouped as radiometric or geometric correlations. Geometric correlations include correlating for geometric distortions due to sensor – earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the earth's surface.

Geometric registration process involves identifying the image coordinates (i.e. row, column) of several clearly discernible points, called ground control points (or GCPs), in the coordinates (e.g. latitude, longitude). The true ground coordinates are typically measured from a map either in paper, digital format or collected with GPS in the field, this is called image – to – map registration. Once several well – distributed GCP pairs have been identified, the coordinate information is processed by the computer to determine the proper transformation equations to apply to the original (row and column) image coordinates to map them into their new ground coordinates. Geometric registration may also be performed by registering one (or more) images to another image, instead of to geographic coordinates, this is called image – to – image registration. All satellite images are registered using the image to map geocoding – techniques with reference to the WGS – 84 Datum, UTM Map Grids Zone 47 North (Figure 3.3).



(a)



(b)

Figure 3.3 (a) Concept of the image to map registration using ground control points on the 1:50,000 scale topographic map. (b) Geocoded Landsat satellite image.

3.2.2 Image Enhancement

Enhancements are used to make it easier for visual interpretation and understanding of imagery for specific applications. Image enhancement is the modification of an image in order to alter its impact on the viewer. Generally, image enhancements change the original digital data values, and it should be carried out after geo – coding. Image enhancement is able to highlight features of thematic interest (lithology, lineaments, land use / land cover, etc) and to suppress redundant information.

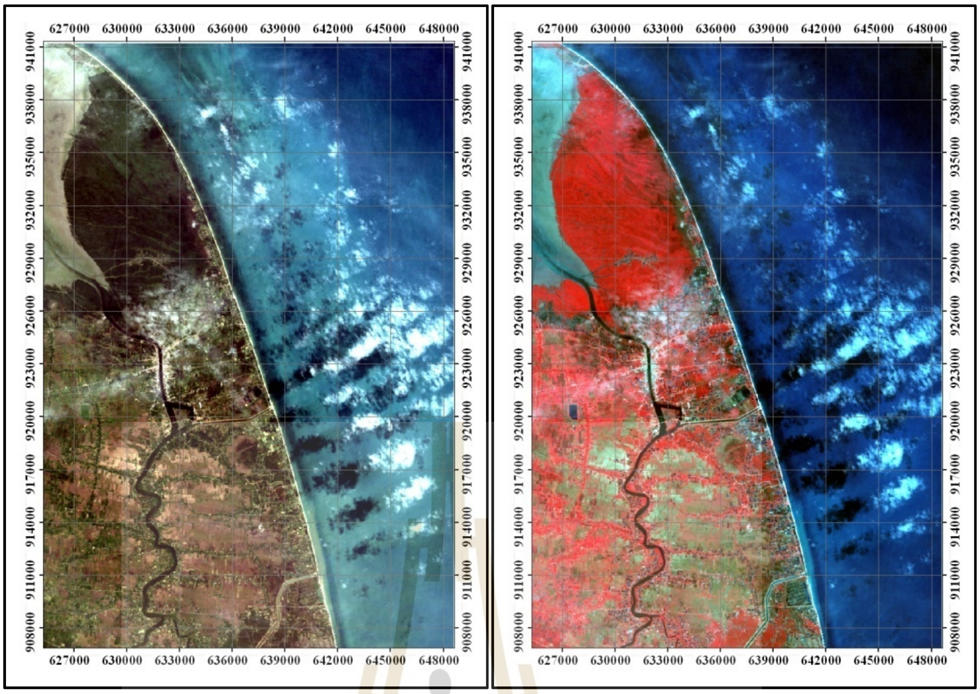
RGB Combination: A multispectral image consists of several bands of data. For visual display, each band of the image may be displayed one band at a time as a grey scale image, or in combination of three bands at a time as a color composite image. Interpretation of a multispectral color composite image will require the knowledge of the spectral reflectance signature of the targets in the scene. The spectral information content of the image is utilized in the interpretation.

In displaying a color composite image, three primary colors (red, green and blue) are used. When these three colors are combined in various proportions, they produce different colors in the visible spectrum. Associate each spectral band (not necessarily a visible band) to a separate primary color results in a color composite image.

If a multispectral image consists of the three visual primary color bands (red, green, blue), the three bands may be combined to produced a "true color" image. For example, the bands 3 (red band), 2 (green band) and 1 (blue band) of a Landsat image can be assigned respectively to the R, G, and B colors for display

(Figure 3.4(a)). In this way, the colors of the resulting color composite image resemble closely what would be observed by the human eyes.

The display color assignment for any band of a multispectral image can be done in an entirely arbitrary manner. The color of a target in the displayed image does not have any resemblance to its actual color. For example, the bands 4 (red band), 3 (green band) and 2 (blue band) of a Landsat image can be assigned respectively to the R, G, and B colors for display (Figure 3.4(b)). The resulting product is known as a false color composite image. There are many possible schemes of producing false color composite images. However, some scheme may be more suitable for detecting certain objects in the image. This false color composite scheme allows vegetation to be detected readily in the image. In this type of false color composite images, vegetation appears in different shades of red depending on the types and conditions of the vegetation, since it has a high reflectance in the NIR band (as shown in the graph of spectral reflectance signature). Clear water appears dark – bluish (higher green band reflectance), while turbid water appears cyan (higher red reflectance due to sediments) compared to clear water. Bare soils, roads and buildings may appear in various shades of blue, yellow or grey, depending on their composition.



(a) (b)

Figure 3.4 (a) RGB composite images showing in natural – like color based on bands 3 (red band), 2 (green band) and 1 (blue band) and (b) RGB composite images showing in false color composite based on bands 4 (red band), 3 (green band) and 2 (blue band), (Landsat P128R54 date 200040810).

3.2.3 Image Transformations

Image transformations are operations similar in concept to those for image enhancement. However, unlike image enhancement operations which are normally applied only to a single channel of data at a time, image transformations usually involve combined processing of data from multiple spectral bands. Arithmetic operations (i.e. subtraction, addition, multiplication, division) are performed to combine and transform the original bands into "new" images which better display or highlight certain features in the scene. We will look at some of these operations including various methods of spectral or band ratio, and a procedure called principal component analysis which is used to more efficiently represent the information in multichannel imagery.

Image Division or spectral ratio is one of the most common transforms applied to image data. Image ratio serves to highlight subtle variations in the spectral responses of various surface covers. By rationing the data from two different spectral bands, the resultant image enhances variations in the slopes of the spectral reflectance curves between the two different spectral ranges that may otherwise be masked by the pixel brightness variations in each of the bands. The following example illustrates the concept of spectral ratio. Healthy vegetation reflects strongly in the near – infrared portion of the spectrum while absorbing strongly in the visible red. Other surface types, such as soil and water, show near equal reflectance in both the near – infrared and red portions. Thus, a ratio image of Landsat 7 Band 5 divided by Band 2 would result the water body it has appeared as dark. Because water is a strong absorber in near IR region and higher reflectance in band 5 regions. It can be useful for discriminating water bodies from land (Alesheikh, 2007) (Figure 3.5(a)).

More complex ratios involving the sums of and differences between spectral bands for various sensors have been developed for monitoring vegetation conditions. One widely used image transform is the Normalized Difference Vegetation Index (NDVI = Band 4 – Band 3 / Band 4 + Band 3) is used to detect vegetation conditions in the study area. The ranges of NDVI are zero (0) to one (1). When the land is free of vegetation, the NDVI value is assigned to zero, and when the land is covered with full vegetation, the NDVI approaches one.

The Normalized Difference Water Index (NDWI = Green – NIR / Green + NIR) is a new method that has been developed to delineate open water features and enhance their presence in remotely – sensed digital imagery (Zhang, 2009). The NDWI makes use of reflected near – infrared radiation and visible green light to enhance the presence of such features while eliminating the presence of soil and terrestrial vegetation features. It is suggested that the NDWI may also provide researchers with turbidity estimations of water bodies using remotely – sensed digital data (Figure 3.5(b)).

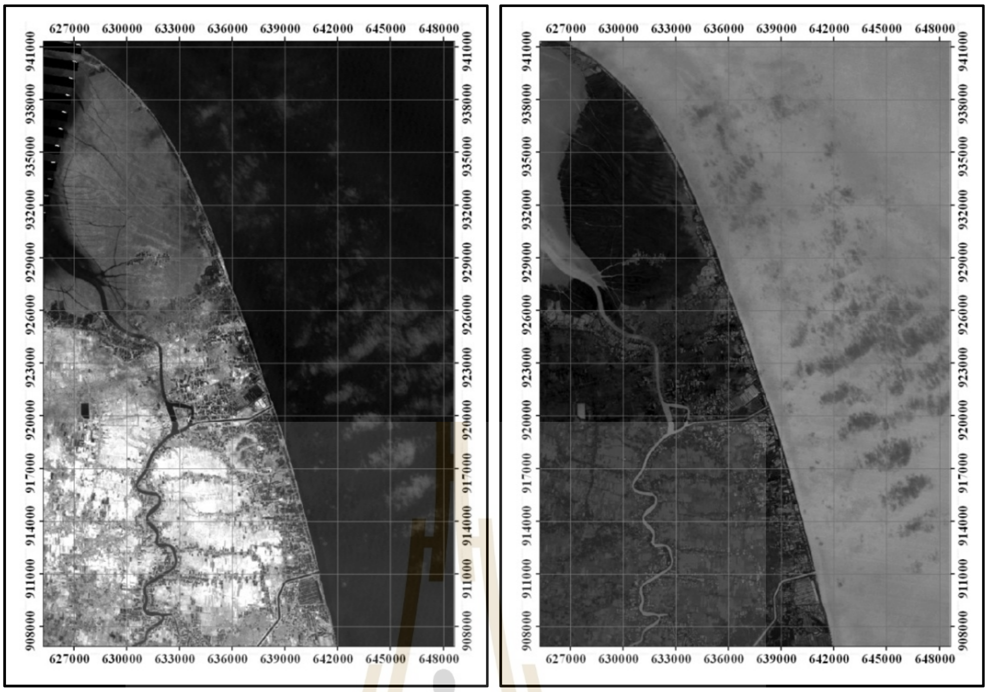


Figure 3.5 (a) Band 5 divided by Band 2 is result of water body, it has appeared as dark tone and (b) The Normalized Difference Water Index (NDWI) is to delineate open water features (Landsat P128R54 date 200040810).

3.2.4 Image Interpretation

Image interpretation is the processes of detection, identification, description, and assessment of significant of an object and pattern imaged. The method of data interpretation for gathering this information can be divided into visual interpretation and automatic interpretation. Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of tone, shape, size, pattern, texture, shadow, and association.

– **Tone** refers to the relative brightness or color of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Variations in tone also allow the elements of shape, texture, and pattern of objects to be distinguished.

– **Shape** refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts. Farm or cropland irrigated by rotating sprinkler systems would appear as circular shapes.

– **Size** of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. A quick approximation of target size can direct interpretation to an appropriate result more quickly.

– **Pattern** refers to the spatial arrangement of visibly discernible objects. Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern. Orchards with evenly spaced trees, and urban streets with regularly spaced houses are good examples of pattern.

– **Texture** refers to the arrangement and frequency of tonal variation in particular areas of an image. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation. Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands. A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance.

– **Shadow** is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets that may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.

– **Association** takes into account the relationship between other recognizable objects or features in proximity to the target of interest. The identification of features that one would expect to associate with other features may provide information to facilitate identification. In our example, a lake is associated with boats, a marina, and adjacent recreational land.

3.2.4.1 Visual interpretation

The most important characteristics that can be studies on image in visual image interpretation are: shape (outline of individual objects), size, tone (relative brightness or color of objects), texture (frequency of total change), shadows, site (topography or geographic location) and association (occurrence of certain features in relation to others). Interpretation procedure results to information for various areas (urban, sub – urban, rural mountainous, etc.), as well as for a variety of subjects (environmental, geotechnical, hydraulics, road construction, urban, cultural etc.) that can be presented descriptively or / and schematically (points, lines, areas).

In this study, the visual interpretation used the Landsat TM and Landsat 7 satellite images which is FCC images TM 4 / Red, TM 5 / Green, TM 7 / Blue, and TM 4 / Red, TM 3 / Green, TM 2 / Blue as well as natural – like colored composites TM 3 / Red, TM 2 / Green, TM 1 / Blue of Landsat 7 were processed and visualized on the computer screen and as photographic hard copies in given scales. These techniques are equally applicable to other sets of digital image data.

3.2.4.2 Automatic interpretation

The automatic interpretation is a technique of digital processing of remote sensing data. The concept of automatic interpretation is the classification of pixels of the multispectral data set into various thematic groups, based on the multispectral responses. In this case, the spectral response of certain surface materials is used to automatically identify and extract specific pieces of information. Precondition is that the operator instructs the computer which kind of information is required, and which information has to be suppressed.

Image classification operations are used to digitally identify and classify pixels in the data. Classification is usually performed on multi – channel data sets and this process assigns each pixel in an image to a particular class or theme based on statistical characteristics of the pixel brightness values. There are a variety of approaches taken to perform digital classification. We will briefly describe the two generic approaches which are used most often, namely unsupervised and supervised classification. In addition, to explain the decision tree classification, this is technique for classified land and water in coastal area.

1) Unsupervised classification

Unsupervised classification in essence reverses the supervised classification process. Spectral classes are grouped first, based solely on the numerical information in the data, and are then matched by the analyst to information classes. Programs, called clustering algorithms, are used to determine the natural (statistical) groupings or structures in the data. Usually, the analyst specifies how many groups or clusters are to be looked for in the data. In addition to specifying the desired number of classes, the analyst may also specify parameters related to the separation distance among the clusters and the variation within each cluster. The final result of this iterative clustering process may result in some clusters that the analyst will want to subsequently combine, or clusters that should be broken down further – each of these requiring a further application of the clustering algorithm. Thus, unsupervised classification is not completely without human intervention. In this case study, unsupervised classification process was conducted using the ENVI ISO – data cluster analysis tool.

2) Supervised classification

Supervised classification, the analyst identified in the imagery homogeneous representative samples of the different surface cover types (information classes) of interest. These samples are referred to as training areas or regions of interest (ROIs) in Figures 3.6. The selection of appropriate training areas is based on the analyst's familiarity with the geographical area and their knowledge of the actual surface cover types present in the image. Thus, the analyst is "supervising" the categorization of a set of specific classes. The numerical information in all spectral bands for the pixels comprising these areas is used to "train" the computer to recognize spectrally similar areas for each class. The computer used a special program or algorithm (of which there are several variations), to determine the numerical "signatures" for each training class. Once the computer has determined the signatures for each class, each pixel in the image is compared to these signatures and labeled as the class it most closely "resembles" digitally. Thus, in a supervised classification we are first identifying the information classes which are then used to determine the spectral classes which represent them (Figure 3.7).

3) Decision Tree Classification

Decision tree classification is one of the inductive learning algorithms that generates classification tree using the training data or samples. It is based on the "divide and conquer" strategy. It is a non parametric in nature hence independent of the properties of the distribution of data, thus suitable for incorporation of non – spectral data into classification procedure so improvement in class separability can be achieved. The resulting decision tree provides a representation of the concept that appeal to human because it renders the classification process self – evident. It supports classification problems with more than two classes. Decision tree classification follows a hierarchical structure where at each level a test is applied to one or more attribute values that may have one of two outcomes. In order to classify an object, we start at the root of the tree, evaluate the test, and take the branch appropriate to the outcome. The process continues until a leaf is encountered, at which time the object is asserted whether it belongs to the class named by the leaf. Each final leaf will be the result of following set of mutually exclusive decision rules down the tree. The tree is expanded until every training instance is correctly classified; over fitting of data is avoided by pruning the training dataset. In this study, decision tree classification is useful for indicate coastline in coastal area. The expressions can include math functions, relational operator functions as shown in Table 3.4.

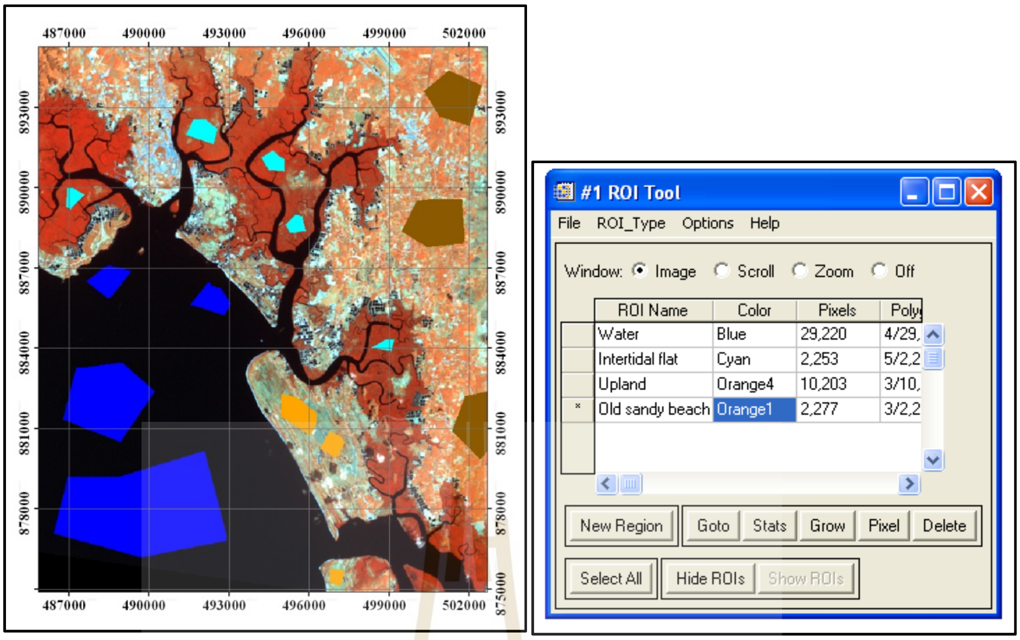


Figure 3.6 Training sites selected for supervised classification on Landsat P129R54, taken on 20004/08/10.

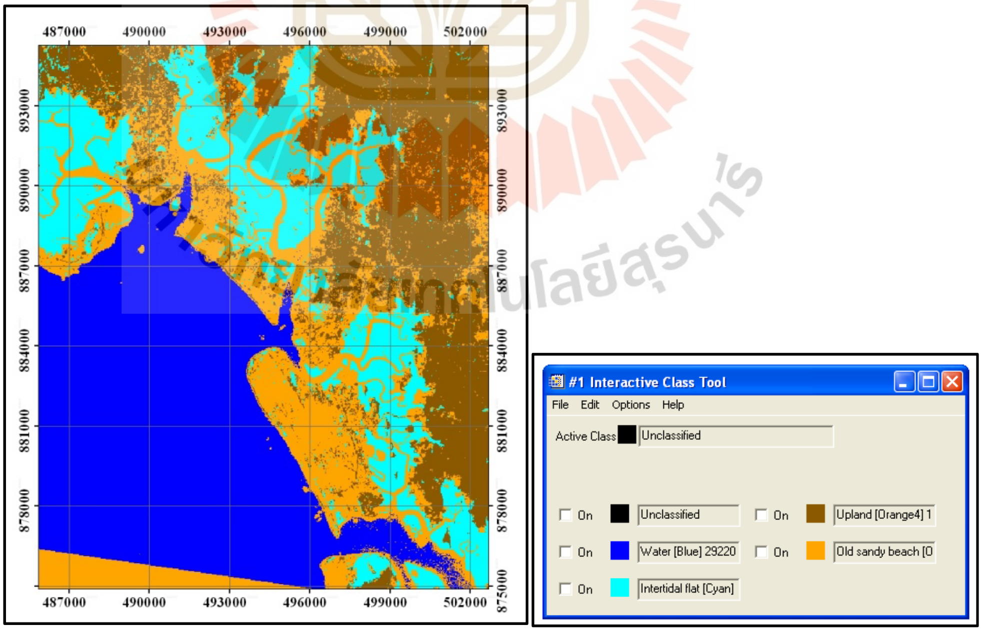


Figure 3.7 Result of the supervised classification for some part of the Krabi Province (Landsat P129R54 date 200010222).

Table 3.4 Expressions functions in Decision tree classification (from ENVI user's manual).

Category	**Available Function**
Basic Arithmetic	Addition (+) Subtraction (-) Multiplication (*) Division (/)
Relational and Logical Operators	Less than (LE) Less than or equal (LT) Equal (EQ) Not equal (NE) Greater than or equal (GE) Greater than (GT) Maximum (>) Minimum (<)

3.2.5 Image Post Classification

Classified images require post – processing to evaluate classification accuracy and to generalize classes for export to image, maps and vector GIS. Post Classification can be used to classify rule images; to calculate class statistics and confusion matrices; to apply majority or minority analysis to classification images; to clump, sieve, and combine classes; to overlay classes on an image; to calculate buffer zone images; to calculate segmentation images; and to output classes to vector layers. In this study focus are follows:

1) Majority or Minority Analysis

Majority or Minority Analysis to applied a post – classification image. Use majority analysis to change spurious pixels within a large single class to that class. Kernel size and the center pixel in the kernel will be replaced with the class value that the majority of the pixels in the kernel has. Minority analysis, then the center pixel in the kernel will be replaced with the class value that the minority of the pixels in the kernel has.

2) Sieve and Clump Classes

Sieve and Clump are used to generalize classification images. Sieve Classes to solve the problem of isolated pixels occurring in classification images. Sieving classes removes isolated classified pixels using blob grouping. Again, low pass or other types of filtering could be used to remove these areas, but the class information would be contaminated by adjacent class codes. The sieve class method looks at the neighboring 4 or 8 pixels to determine if a pixel is grouped with pixels of the same class. If the number of pixels in a class that are grouped is less than the value that you enter, those pixels will be removed from the class. When pixels are removed from a class using sieving, black pixels (unclassified) will be left. Clump Classes to clump adjacent similar classified areas together using morphological operators. Classified images often suffer from a lack of spatial coherency (speckle or holes in classified areas). Low pass filtering could be used to smooth these images, but the class information would be contaminated by adjacent class codes. Clumping classes solves this problem. The selected classes are clumped together by first performing a dilate operation then an erode operation on the classified image using a kernel of the size specified in the parameters dialog.

3) Combine Classes and Changing Colors

The Combine Classes function provides an alternative method for classification generalization. Similar classes can be combined to form one or more generalized classes. Class Color Mapping to change the colors of classes after a classified image is loaded into a display window. The color that a class is automatically displayed in corresponds to the color of the selected ROIs for supervised classification and to preselected class colors for unsupervised classification. Unclassified areas appear black on the images. Class Color Mapping is change classification image colors and class names for individual classes. The changes can be saved to the header file.

3.3 Fieldwork

In this study, fieldwork is an important part of the remote sensing data interpretation. It is crucial precondition for the provision of accurate and reliable interpretation results. Field checking was carried out as follows:

1) Record and documentation of the GCPs with hand – held GPS.
2) Spot – check and verification of image interpretation results.
3) Data and information collection for the automatic image classification.
4) Collected ground truth information for the comparison with the processed satellite images and preliminary products.
5) Collected background information by interviewing locals (on reasons of land use changes, coastal change, etc.).

During the investigations, coastal change recognized on remote sensing data will be verified. Other factors related to coastal change (e.g., geological map, land use map and geomorphologic map) were updated by spot – check depending on accessibility.

3.4 GIS Preparation

This step will describe the technique of GIS database construction conducted in this study. The data sets related to coastal change in the study area were transformed to digital formats and stored as database of GIS. All data sets were built on a raster base and assigned with an attributes database. Each pixel corresponds to a ground resolution cell of 30 meters by 30 meters, and contained the values, symbol and class of data maps. The data maps and its attributes are constructed as a database into the GIS using ArcGis 9.3 software. Database construction is divided into two parts are remote sensing construction and GIS construction (Figure 3.8).

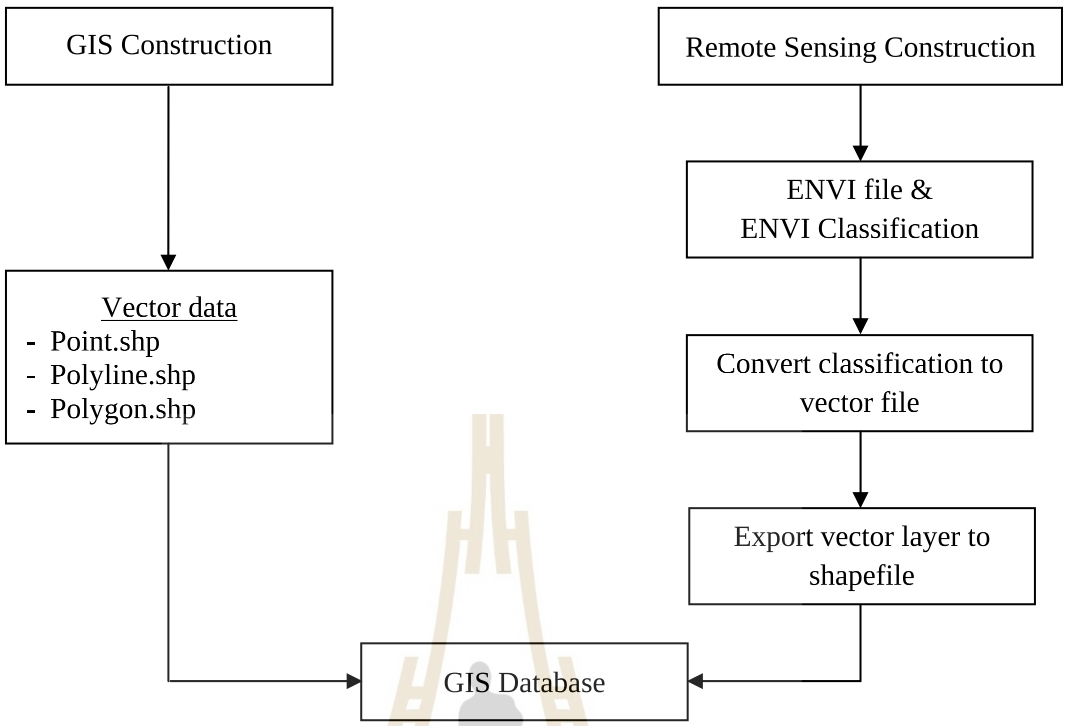


Figure 3.8 Flow chart of database construction.

3.4.1 Remote Sensing Construction

The convert to shapefile of image classification (ENVI file) is necessary use in ArcGis.

1) Convert classification to vector file: When have result of image classification then use the vector menu. This vector menu is process of open vector files, create vector files, manage vector files, and convert raster images (including classification images) to ENVI vector layers. The classification to vector is convert classification results to ENVI polygon vector layers (.evf files). The classification images will have a vector layer for each selected class. If a separate layer for each class is output, each selected class is saved to a separate vector.

2) Export vector layer to shapefile: Use export active layer to shapefile to export vector layers to a shapefile (.shp). Each shapefile can contain only one type of vector (polygon, point, etc.). If multiple vector types are present in the layer being exported, you are prompted to provide different output filenames for each vector type.

3.4.2 GIS Construction

Shape files are a simple format for storing the geometric location and attribute information of geographic features. A shapefile is one of the spatial data formats that you can work with and edit in ArcGIS. The shapefile format defines the geometry and attributes of geographically referenced features in three or more files with specific file extensions that should be stored in the same project workspace. Geographic features in a shapefile can be represented by points, polylines, or polygons (areas). A new shapefile can create on the ArcCatalog in ArcMaps. The new shapefile create be able to select the feature type such as point, polyline, and polygon. Then define the coordinate system of the shapefile. If you choose to define the shapefile coordinate system later, it will be classified as unknown unit.

3.5 Spatial Data Integration for Coastal Change Analysis

Coastal change analysis is particularly concerned with the variation of coastline and geomorphology. As data from a variety of sources has become more easily available, it is highly desirable to investigate a strategy for the integration of multi – spatial data for coastal mapping and change analysis. Integration analysis of spatial data from multiple sources is a field that has become increasingly important in the development of geomatics, particularly its remote sensing and GIS components.

The GIS database is used to produce coastal change map. GIS design involves organizing geographic information into a series of data themes – layers that can be integrated using geographic location. So it makes sense that GIS database design begins by identifying the data themes to be used, then specifying the contents and representations of each thematic layer. Each GIS database can be represented as feature classes (sets of points, lines, and polygons), imagery and raster. The product of the coastal change map consists of the following:

1) **Coastline Map**: The map of coastline serves as the basic data source for understanding coastal change. This map was prepared by automatic interpretation (decision tree classification) of satellite remote sensing imagery and field examination of selected locations. The accurate detection of coastline is very important for study of the coastal change.

2) **Geological Map**: The map is modified from the geological map at the scale 1:50,000 and 1:250,000 published by the Department of Mineral Resources. Then the remote sensing interpretation and fields checking are conducted to verify these maps. In this study, geological map delineates the bedrock and the mapped units are based on rock type, especially the Quaternary for the coastal change study.

3) **Geomorphology Map**: Geomorphological mapping is essential in understanding the coastal change. It is based upon integration of remotely sensed data and field investigation. Geomorphology focuses upon landform description / classification, process characterization and the association between landforms and processes, while remote sensing is able to provide information on the location / distribution of landforms.

3.6 Verification of the Result and Reporting

The verification method is an integration of remote sensing technique, GIS database, field investigation and sieve analysis. The thesis writing has been done.

CHAPTER 4

RESULTS

Thailand comprises extensive coastline totaling about 2,637 kilometers in length (DMR, 2002). The study areas cover coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea.

In this study, the Remote Sensing techniques of ENVI program and GIS techniques of ArcGIS software are used to perform the spatial database for the spatial analysis of coastal change analysis. The data sets related to coastal change in this study were derived from remote sensing data, available maps, and field investigation. The results of coastline analysis are the maps of band ratio and the Normalized Difference Water Index (NDWI). They show the difference of land and water. Then the decision tree classification is applied for classification of the coastline. The comparison of coastlines in different time shows the area of erosion and deposition. In addition, the classification of geomorphology is used to explain the change of the coast.

4.1 Geomorphology of Study Area

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

The geomorphology is defined as the science of landforms with an emphasis on their origin, evolution, form, and distribution across the physical landscape. An understanding of geomorphology and its processes is therefore essential to the understanding of physical geography. Coastal geomorphology, by definition, is the study of the morphological development and evolution of the coast as it acts under the influence of winds, waves, currents, and sea – level changes.

The coastal geomorphology of Thailand is characterized by beach sand, dune, coastal wetland (tidal flat and marshes), rocky coast and cliff coast. The Gulf of Thailand Coast characterized by long and wind mainland beach. Features such as raised beaches with dune, variety of lagoons, tidal flat and marshes were developed. The elevation of coastal areas ranges from 0 – 4 meters above the mean sea – level with minor undulations. The Andaman Sea Coast is dominated by pocket beach, extensive and well preserved tidal flat vegetated with mangrove forest, cliff coast and numerous islands.

These coastal landforms indicated the invasion of Holocene sea which reached the maximum height at about 6,000 years BP. However, there are evidences of Late

Pleistocene marine sediment locally found underlie the Holocene sediment in the Gulf of Thailand Coast. Rocks in the coastal zone range in age from Precambrian to tertiary, including all main rock types. Rocks on the east and west coast of the peninsular are mostly the same units, except the Upper Gulf of Thailand Coast where unconsolidated Quaternary sediments are dominant.

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

Rocky coast: Rocky coasts are reflective coast with high, steep cliffs consisting of consolidated sediments or unconsolidated sediments with different mechanic strengths and an abrasional shore platform at the base which can be covered by clastic deposit forming small pocket – beaches. The height of the cliff is controlled by the nature of the hinterland, i.e. the composition the slope, and the resistance of the rocks to erosion by marine, and continental agents. The main processes acting on rocky coasts are wave and tide dependent.

Tidal Flat: Tidal flats are banks of mud or sand that are exposed at low tide. They are not actually flat but slope very gently towards the sea from the high – tide level down to a little below the low – tide level. A tidal flat can be divided into three parts, according to their relation to the characteristic tidal water levels:

(1). **Old tidal flat**, which is located above the high water on springs and is inundated only under extreme conditions.

(2). **Intertidal flat**, located between the high water and low water on springs and is inundated periodically during spring – neap tidal cycles.

(3). **Sub – tidal flat**, which is below the low water on springs and is rarely exposed in air.

Lagoons: A lagoon is a shallow body of water protected from a larger body of water (usually the ocean) by sandbars, barrier islands, or coral reefs. Lagoons are often called estuaries, sounds, bays, or even lakes. Lagoons sheltered by sandbars or barrier islands are called coastal lagoons. Coastal lagoons form along coastal plains – flat or gently sloping landscapes. They form in areas with small tidal ranges. Coastal lagoons are created as a shallow basin near the shore gradually erodes, and the ocean seeps in between the sandbars or barrier islands. The lagoon is divided into two parts (Sinsakul, 2002) are following

(1). **Old lagoons** are generally about 6,000 – 10,000 years old, having formed where valley mouths or lowlands have been submerged by the sea during the later stages of the world – wide Holocene marine transgression. Lagoons that were enclosed by Pleistocene barriers drained out during the Last Glacial low sea level phase, leaving subaerial basins that were flooded when the sea rose again. Sediments are almost sand inter – bedded clay and in the present day this area is a paddy field or sedge cover.

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

Marsh: Marsh is a type of wetland in coastal area. That is continuous evaluation from old tidal flat, delta and lagoon. Marshes are most commonly found in lagoons, estuaries and on the sheltered side of shingle or sand spit. The currents there carry the fine particles around to the quiet side of the spit and sediment begins to build up.

Sandy Beach: A sand beach is a beach consisting primarily of sand. This sand movement is caused by the waves that constantly break along coasts. Every wave shifts the sand and changes in the size of the waves and the direction of the waves increases or decreases the intensity of this sand movement. The sandy beach is divided into two parts (Sinsakul, 2002) are following.

(1). **Old sandy beach** is generated from transgressive sediment in 6,000 years ago an elevation is 4 – 5 meters above mean sea level and far from the present coastline, now this area is the settlement area.

(2).**Young sandy beach** is located along the coastline and elevation about 0.5 – 2 meters above mean sea level.

4.1.1 Gulf of Thailand Sea Coast

The Gulf of Thailand coast is represented by old tidal flat, intertidal flat, sub – tidal flat, old and young lagoons, marsh, old and young sandy beach shown in Figure 4.1 – 4.12.

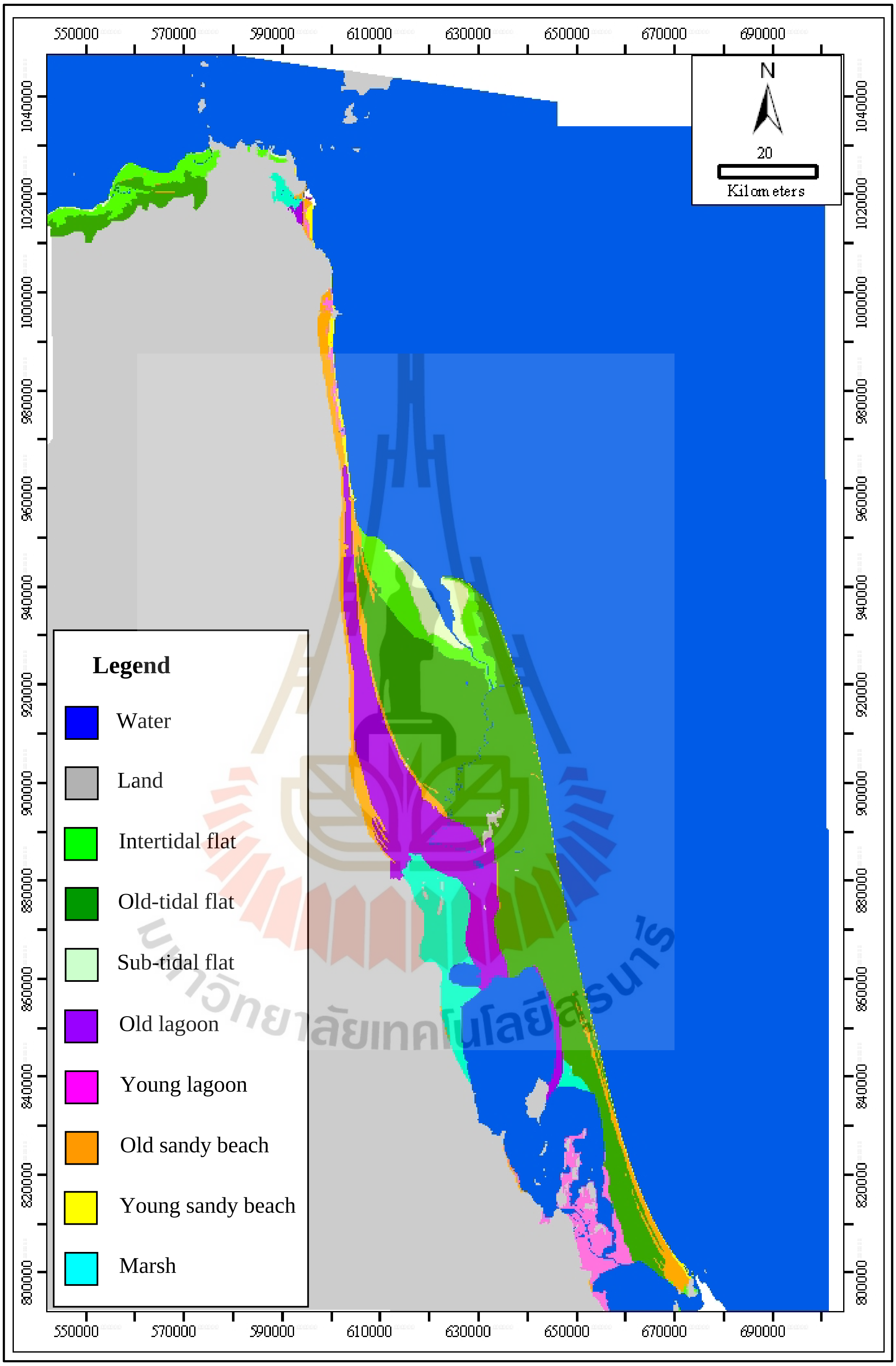


Figure 4.1 Coastal geomorphologic map of the Gulf of Thailand.

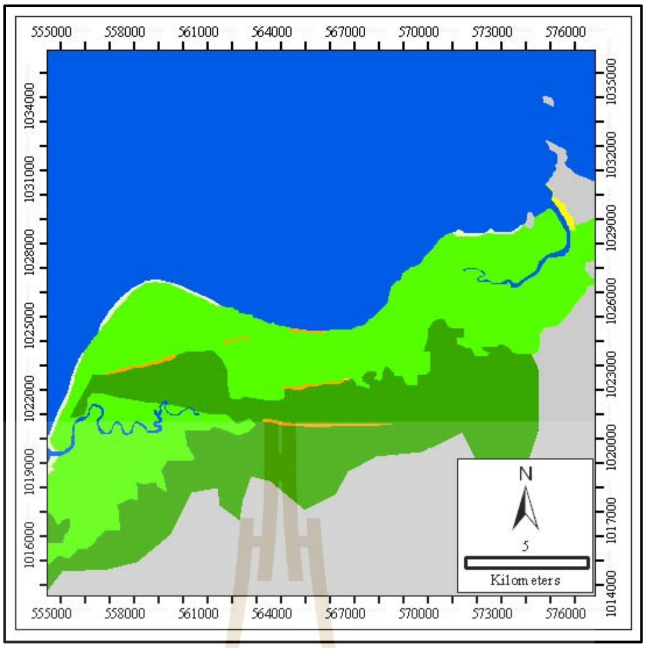


Figure 4.2 Coastal geomorphologic map of the Kanchanadit and Donsak districts, Surat Thani province.

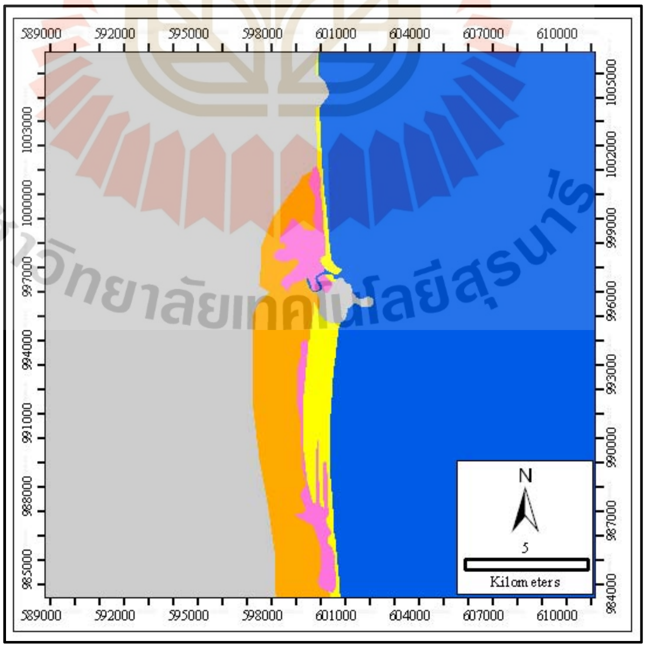


Figure 4.3 Coastal geomorphologic map of the Sichon district, Nakhon Si Thammarat province.

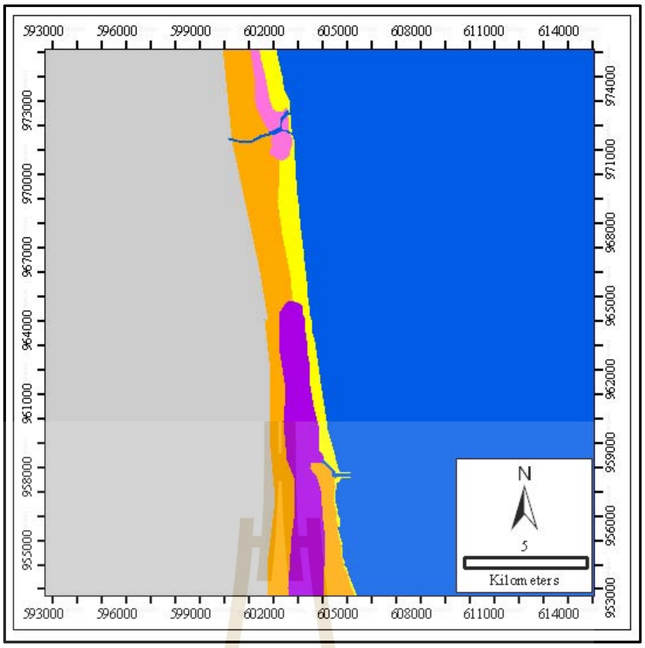


Figure 4.4 Coastal geomorphologic map of the Thasala district, Nakhon Si Thammarat province.

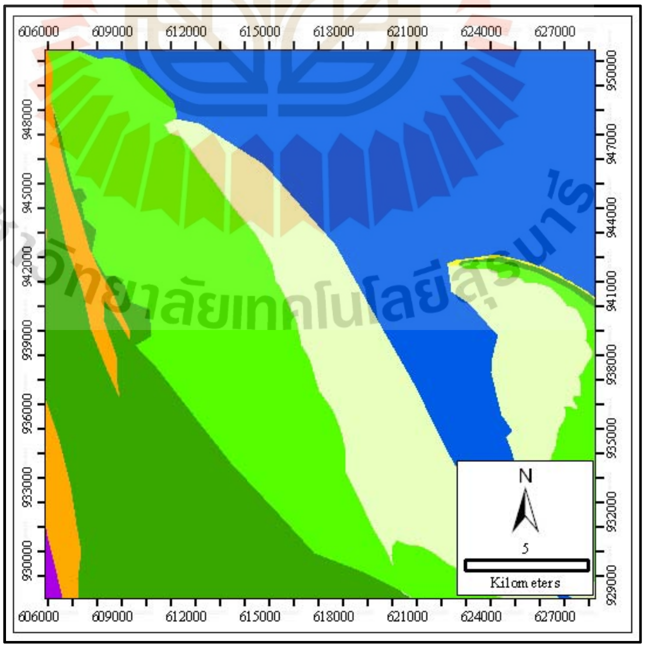


Figure 4.5 Coastal geomorphologic map of the Muang district, Nakhon Si Thammarat province.

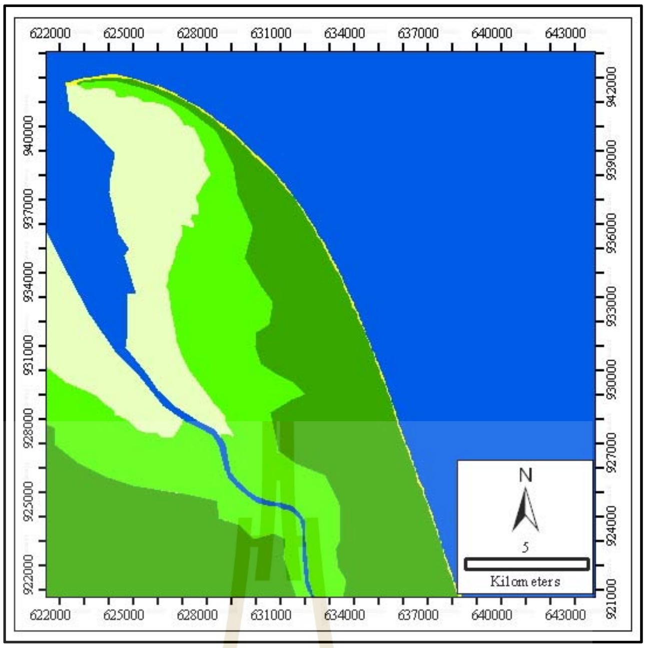


Figure 4.6 Coastal geomorphologic map of the Pak Panang district, Nakhon Si Thammarat province.

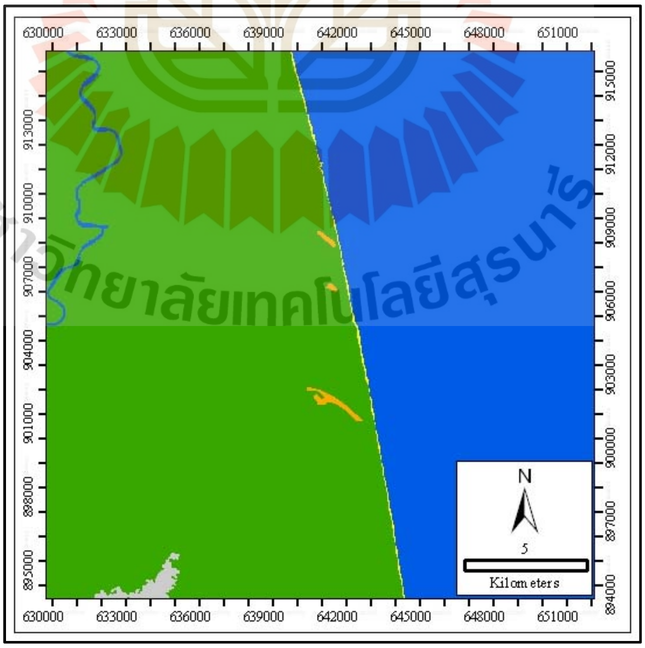


Figure 4.7 Coastal geomorphologic map of the Pak Panang and Hua Sai districts, Nakhon Si Thammarat province.

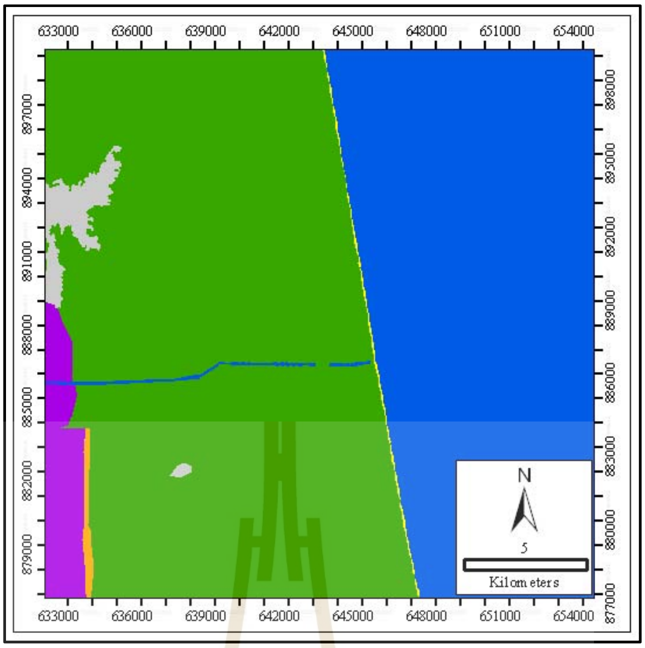


Figure 4.8 Coastal geomorphologic map of the Hua Sai district, Nakhon Si Thammarat province.

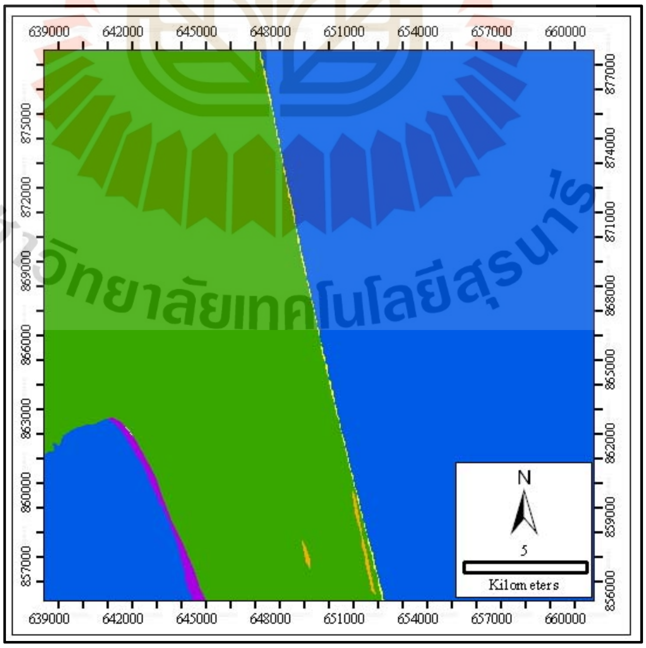


Figure 4.9 Coastal geomorphologic map of the Ranot district (upper part), Songkhla province.

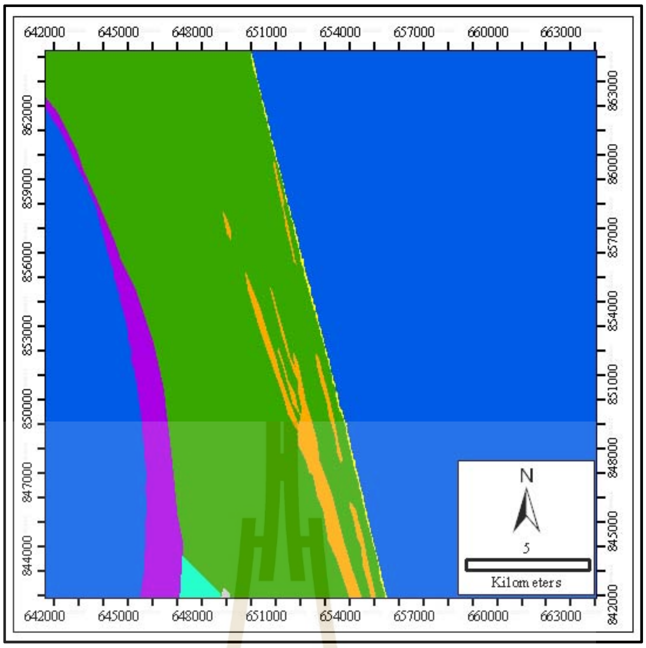


Figure 4.10 Coastal geomorphologic map of the Ranot district (lower part), Songkhla province.

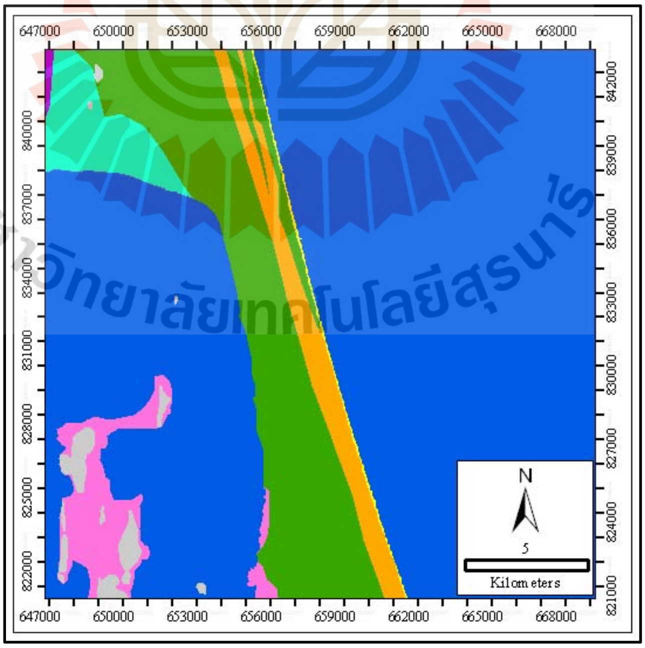


Figure 4.11 Coastal geomorphologic map of the Satingphra district, Songkhla province.

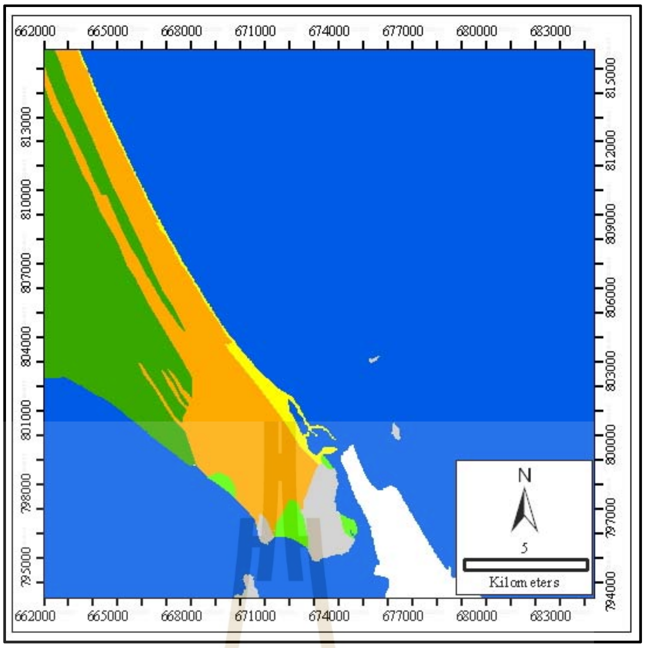


Figure 4.12 Coastal geomorphologic map of the Singhanakhon district, Songkhla province.

4.1.2 Andaman Sea Coast

The result of the geomorphological study indicates that the Andaman sea coast is characterized by rocky coast, intertidal flat and old and young sandy beach shown in Figure 4.13 – 4.25.

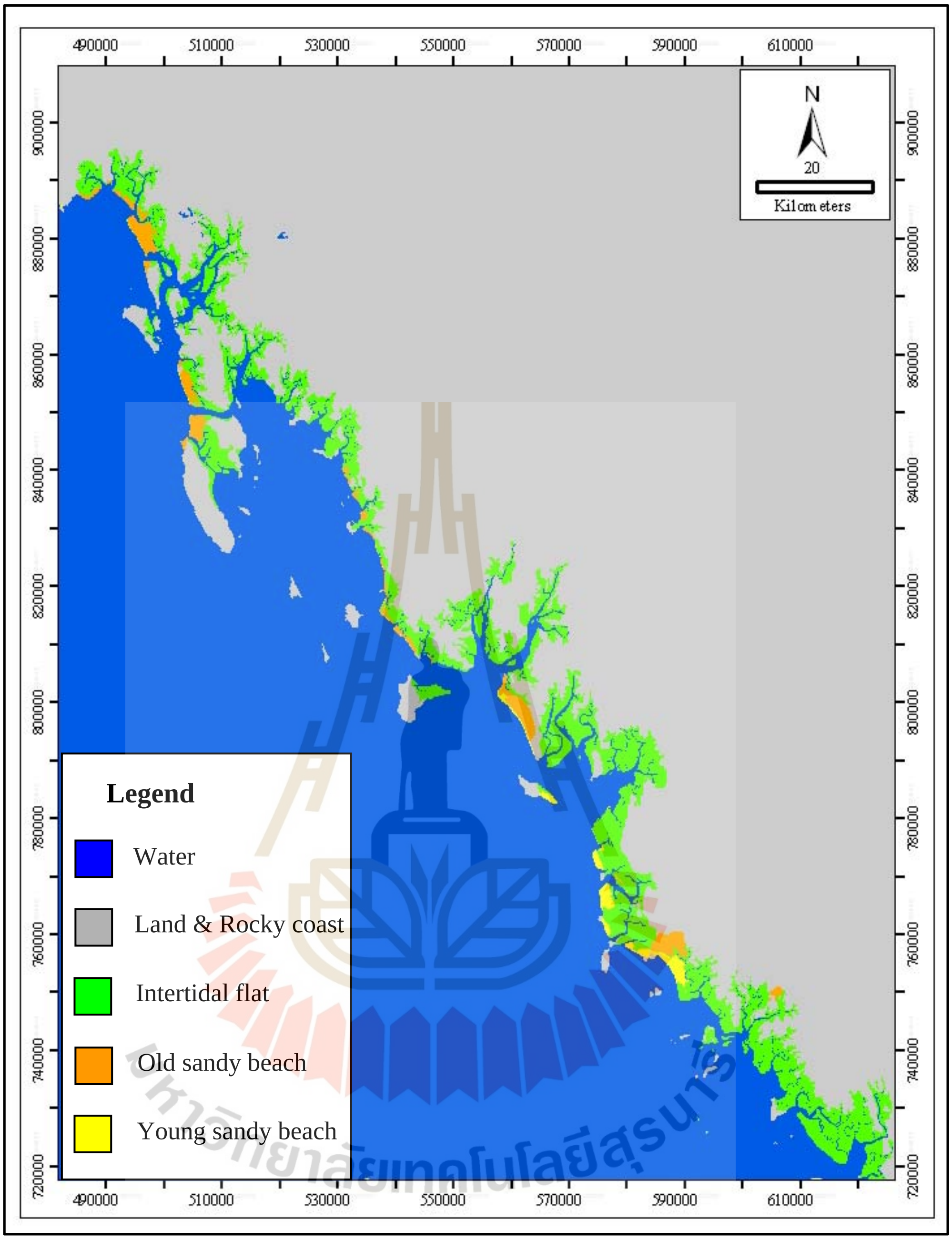


Figure 4.13 Coastal geomorphologic map of the Andaman Sea.

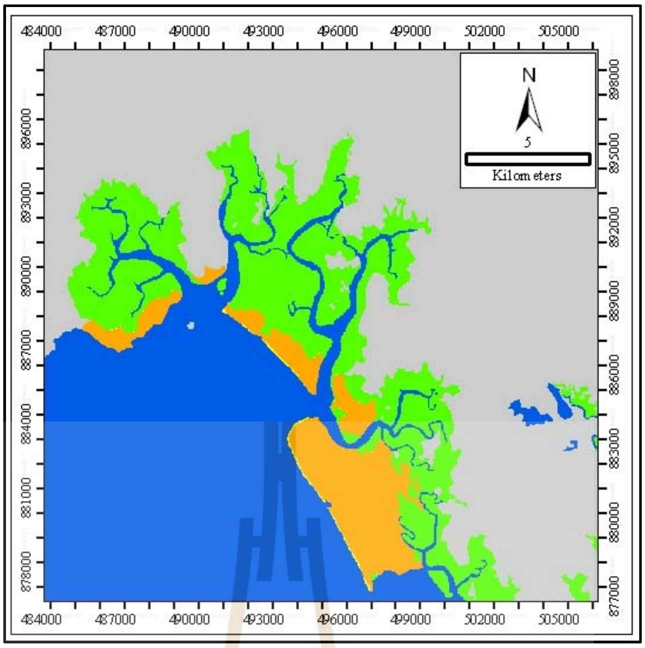


Figure 4.14 Coastal geomorphologic map of the Muang and Nua Khlong districts, Krabi province.

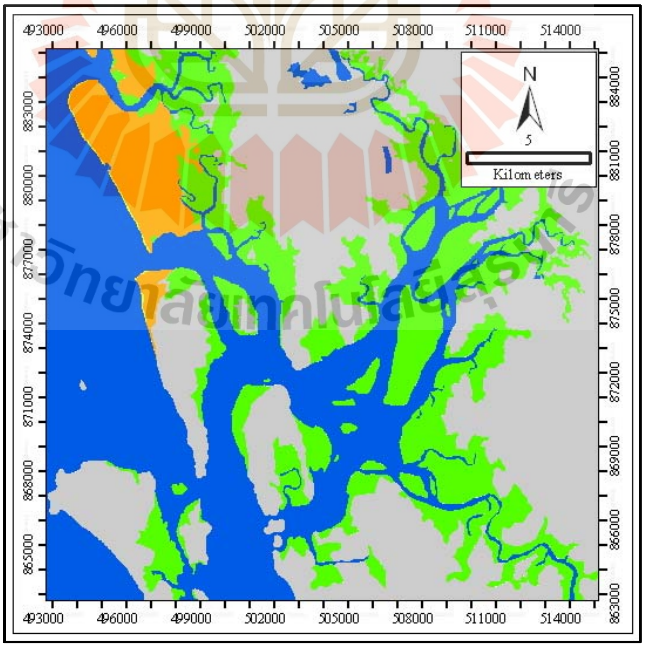


Figure 4.15 Coastal geomorphologic map of the Nua Khlong and Khlong Thom districts, Krabi province.

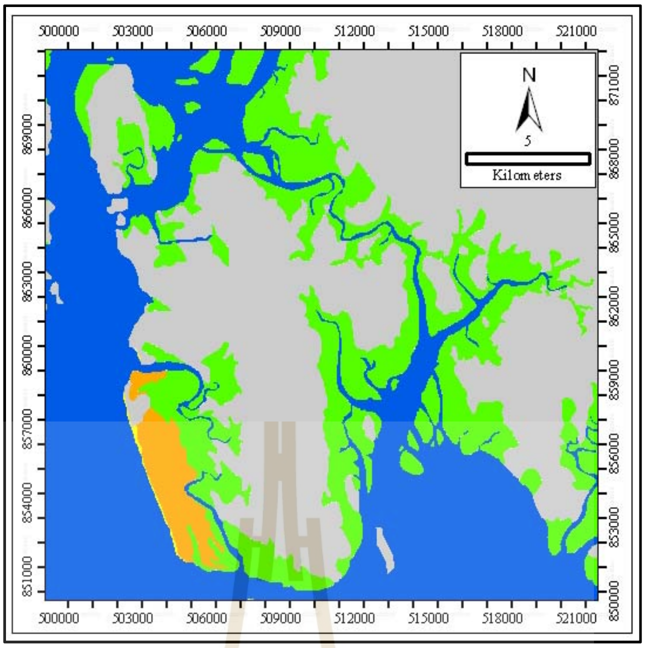


Figure 4.16 Coastal geomorphologic map of the Khlong Thom and Lanta districts, Krabi province.

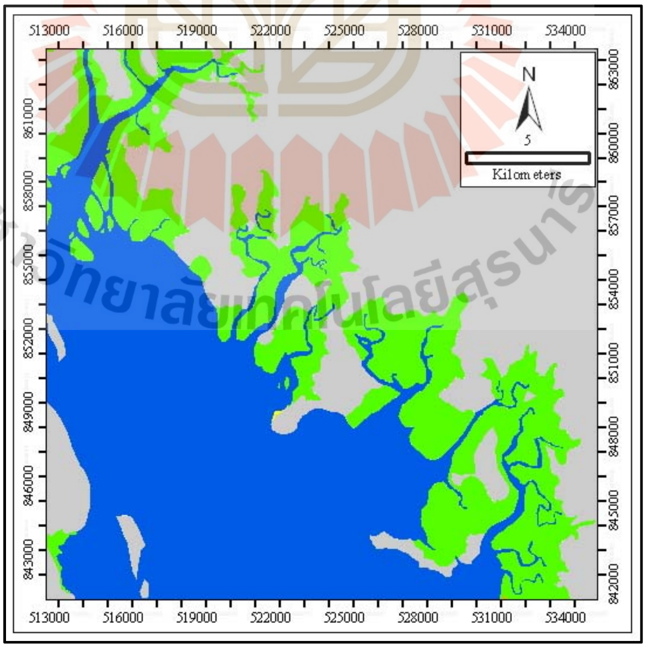


Figure 4.17 Coastal geomorphologic map of the Khlong Thom district, Krabi province.

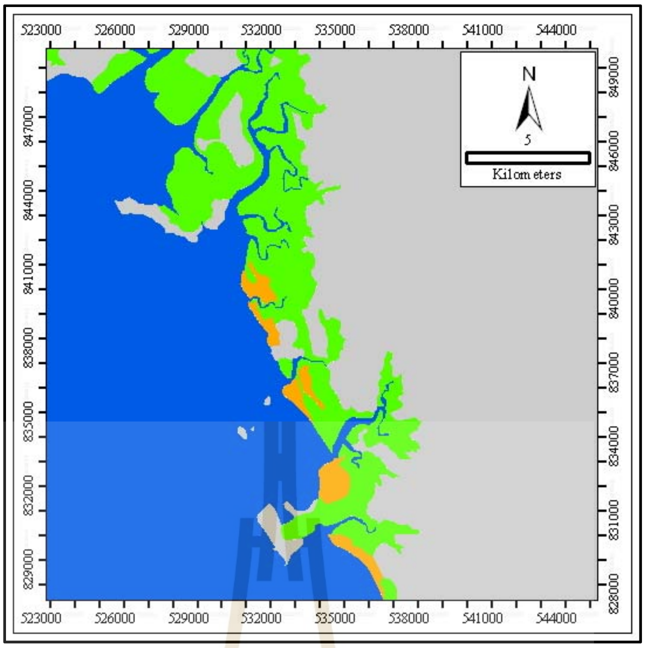


Figure 4.18 Coastal geomorphologic map of the Sikao district (upper part), Trang province.

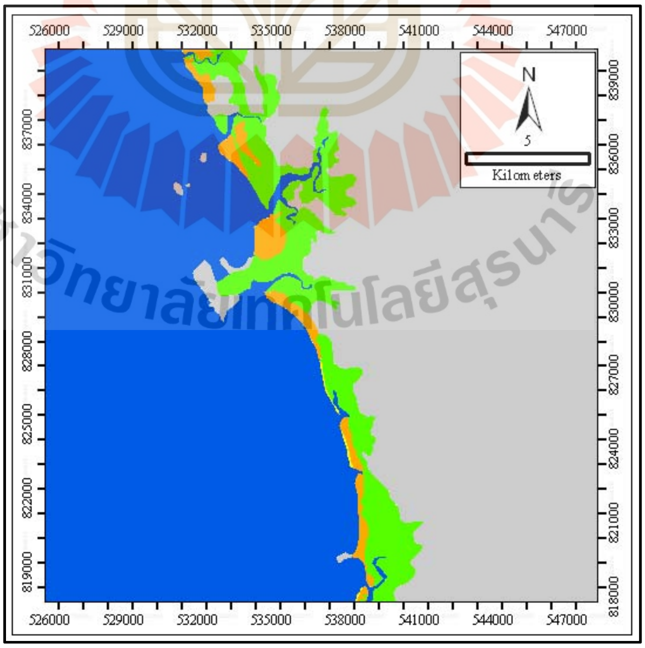


Figure 4.19 Coastal geomorphologic map of the Sikao district (lower part), Trang province.

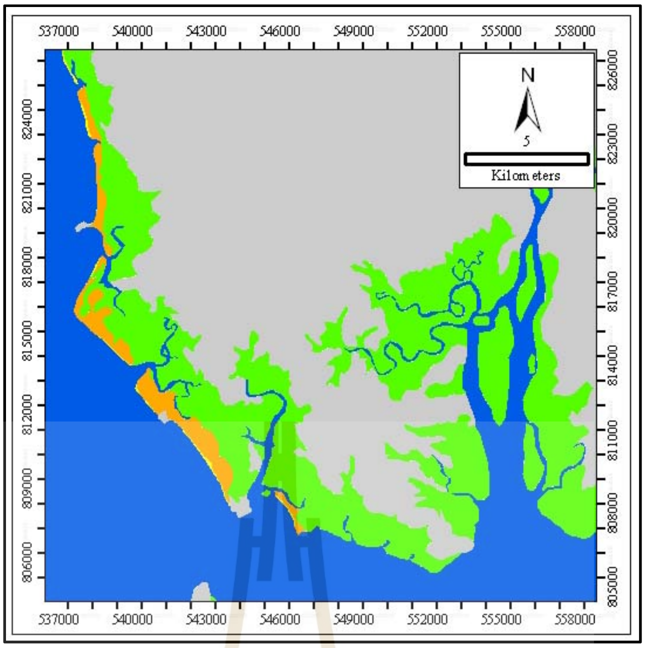


Figure 4.20 Coastal geomorphologic map of the Kantang district, Trang province.

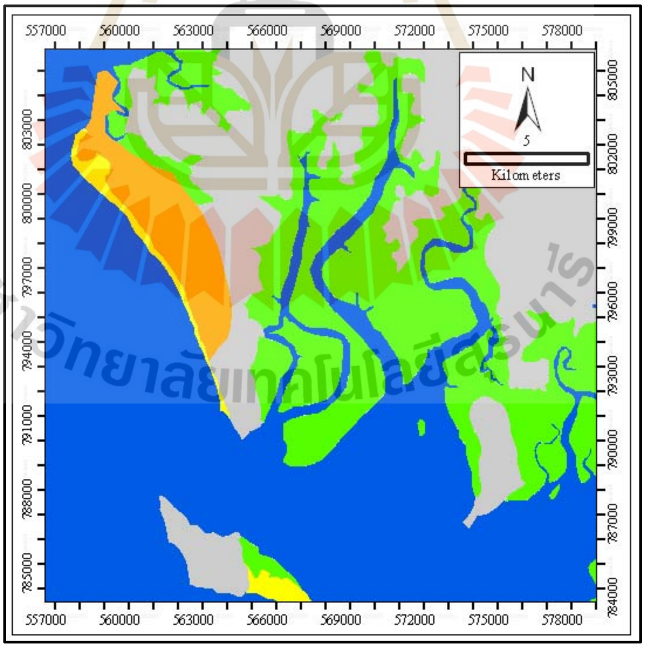


Figure 4.21 Coastal geomorphologic map of the Hat Samran and Palean districts, Trang province.

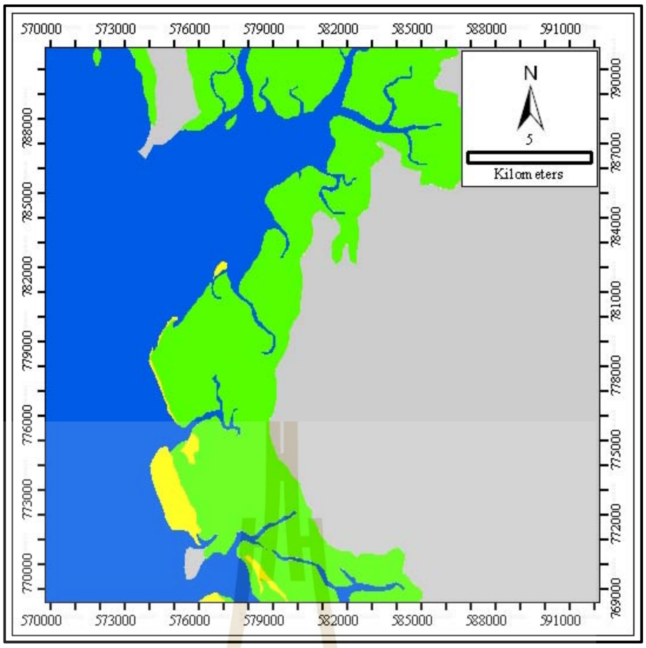


Figure 4.22 Coastal geomorphologic map of the Thung Wa district, Satun province.

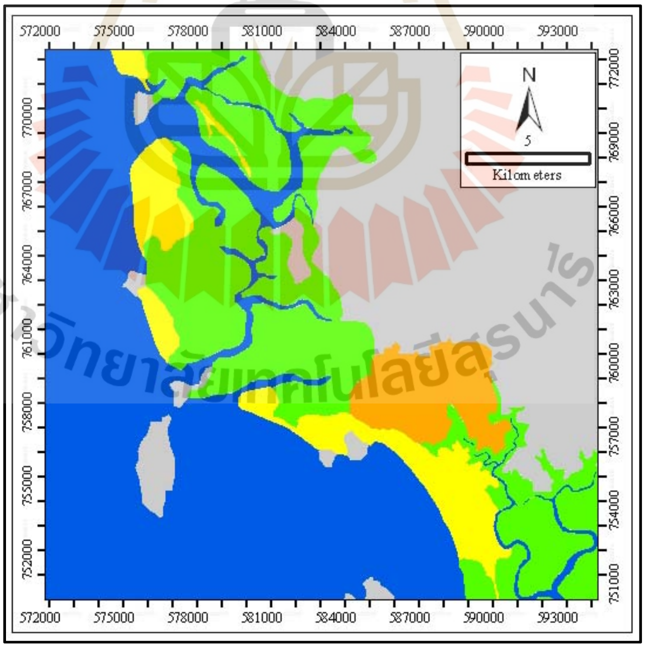


Figure 4.23 Coastal geomorphologic map of the La Ngu district, Satun province.

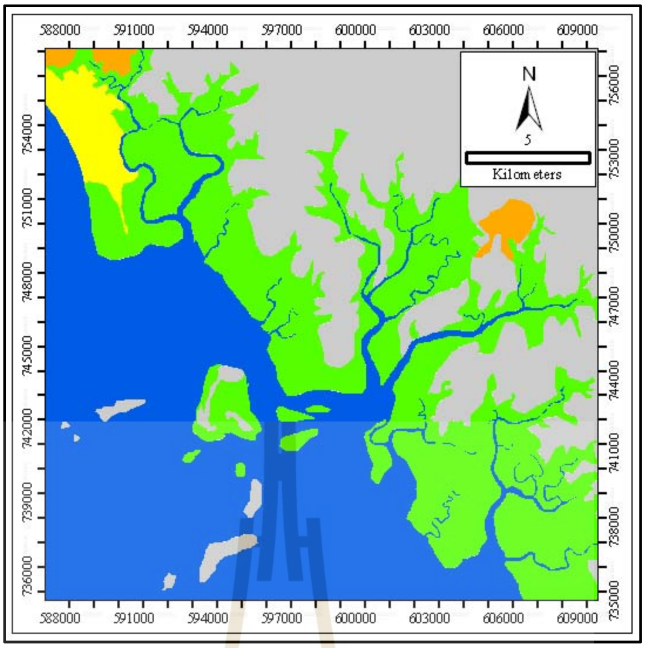


Figure 4.24 Coastal geomorphologic map of the Tha Phae district, Satun province.

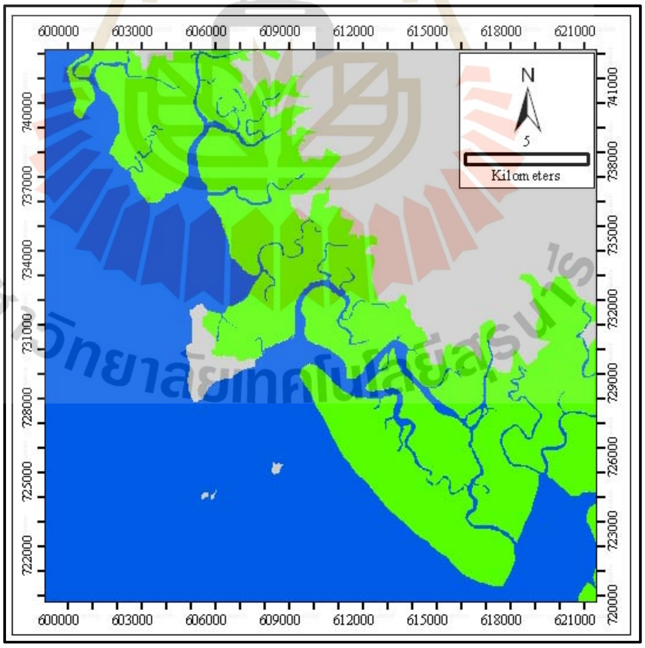


Figure 4.25 Coastal geomorphologic map of the Muang district, Satun province.

4.2 Coastline Verification of Study Area

The image transformations of remote sensing data processing involve combined processing of data from multiple spectral bands. Arithmetic operations (i. e. subtraction, addition, multiplication, division) are performed to combine and transform the original bands into “new” images which better display or highlight certain features in the scene. These operations including various methods of spectral or band ratio are used more efficiently than the multichannel imagery. In this study image transformation techniques are used for classification of land and water and for identification of the coastline.

4.2.1 Band Ratio

Image division or spectral band ratio is one of the most common mathematical operations applied to multi – spectral image data. Ratio images are calculated as the division of Digital Number (DN) values in one spectral band by the corresponding pixel value in another band. Band ratio operation can reduce the environmentally induced variations in the DN values of a single band, such as brightness variations caused by topographic slope and aspect, shadows or seasonal changes in sunlight illumination angle and intensity. Therefore, band ratio tends to emphasize and highlight subtle variations in the actual spectral responses of various surface covers.

Generally water bodies reflect high in the visible spectrum however, clearer water has less reflectance than turbid water. In the Near IR and Mid – IR regions water increasingly absorbs the light making it darker. This is dependent upon water depth and wavelength. Increasing amounts of dissolved inorganic materials in water bodies tend to shift the peak of visible reflectance toward the red region from the green region (clearer water) of the spectrum.

Landsat band 5 (1.55 – 1.75 µm) is the best for extracting the land – water interface. Band 5 exhibits a strong contrast between land and water features due to the high degree of absorption of mid – Infrared (IR) energy by water (even turbid water) and strong reflectance of mid – IR by vegetation and natural features in this range. Band 5 has separated water body (dark tone) from barren lands, croplands, and grass lands (lighter tone). The transition zone is the effect of mixed pixels and moisture regimes between land and water. If the reflectance values are sliced to two discrete zones, water (low values) and land (higher values) can be depicted. But the difficulty of this method is to find the exact value, as any threshold value will be exact on some area. Landsat band 2 (0.52 – 0.60 µm) is sensitive to water turbidity differences; it highlighted the turbid water. Another method is to use the band ratio between band 5 and 2. With this method water and land can be separated directly. The ratio of band 5 / band 2 is less than one for water and greater than one for land in large areas of coastal zone. This ratio prefers an algorithm for separating water from land from Landsat TM or ETM+ imagery. This law is exact in coastal zones covered by soil, but not in land with vegetative cover. Actually, this law mistakenly assigns some of the vegetative lands to water. To solve this problem, the two ratios are combined in this investigation. Applying this method, the coastline can be extracted with higher accuracy. In the image ratio of Landsat band 5 divided by band 2, the water body would appear dark. Because water is a strong absorber in Near IR region and higher reflectance in band 5 regions. It can be useful for discriminating water bodies from land.

The study areas cover the coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea. The classification of land and water bodies in these study areas, using band ratio methods is shown in Figure 4.26 – 4.31. The water body is appeared darker than land body.

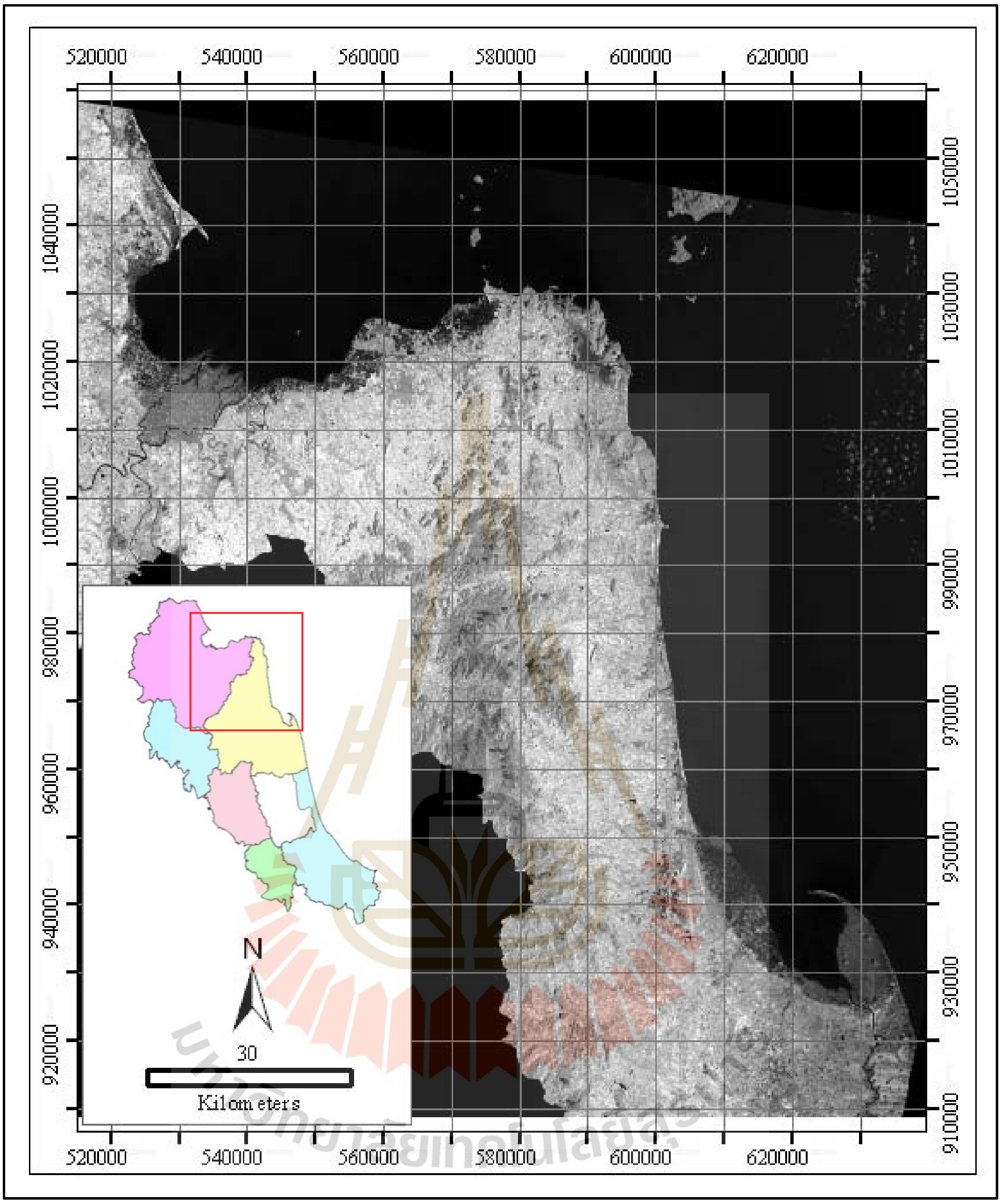


Figure 4.26 Map of Band5 divide Band 2 in Path 129 Row 54 taken on 22/02/2001 shows the result of water body

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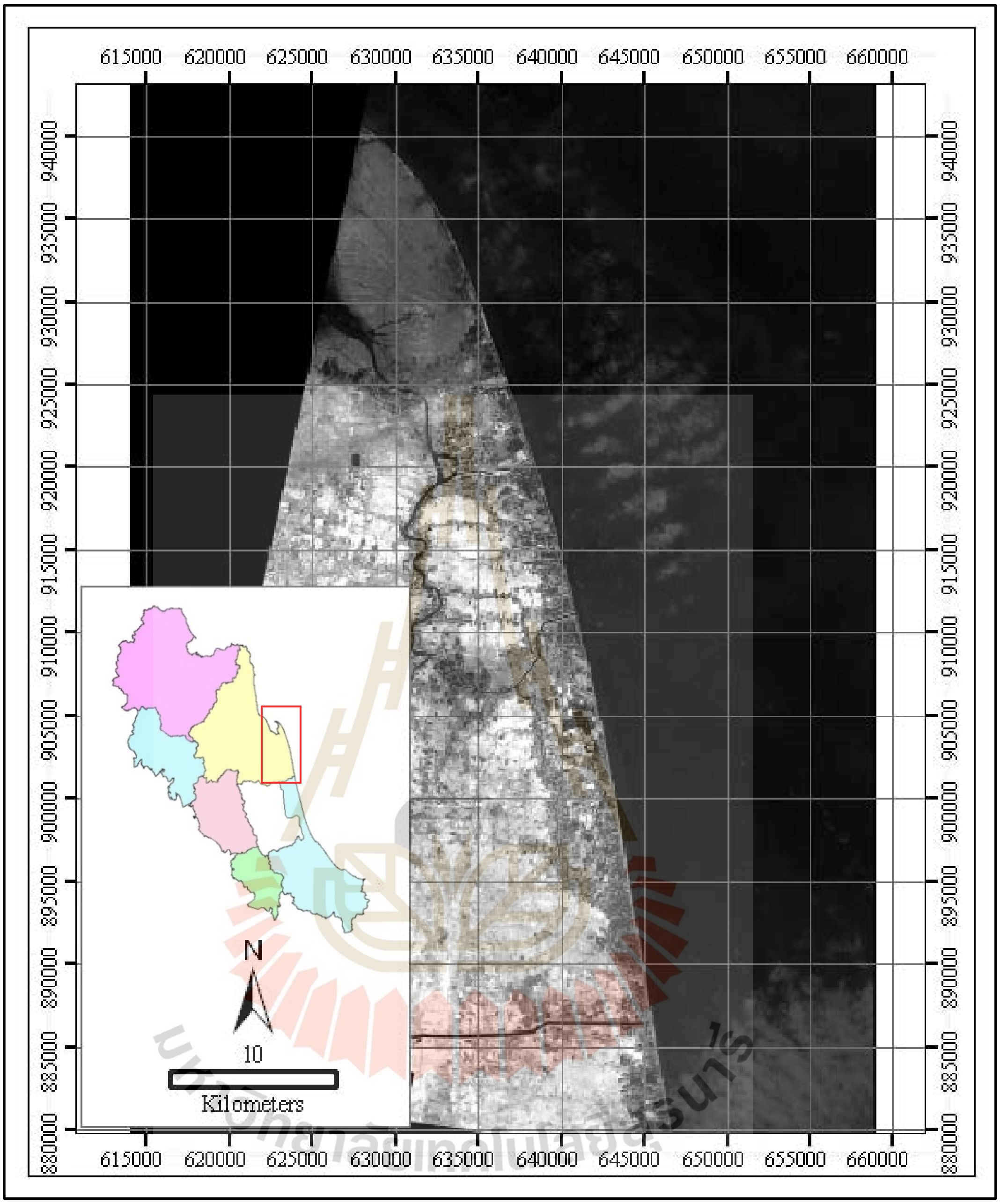

Figure 4.27 Map of Band5 divide Band 2 in Path 128 Row 54 taken on 10/08/2004 shows the result of water body.

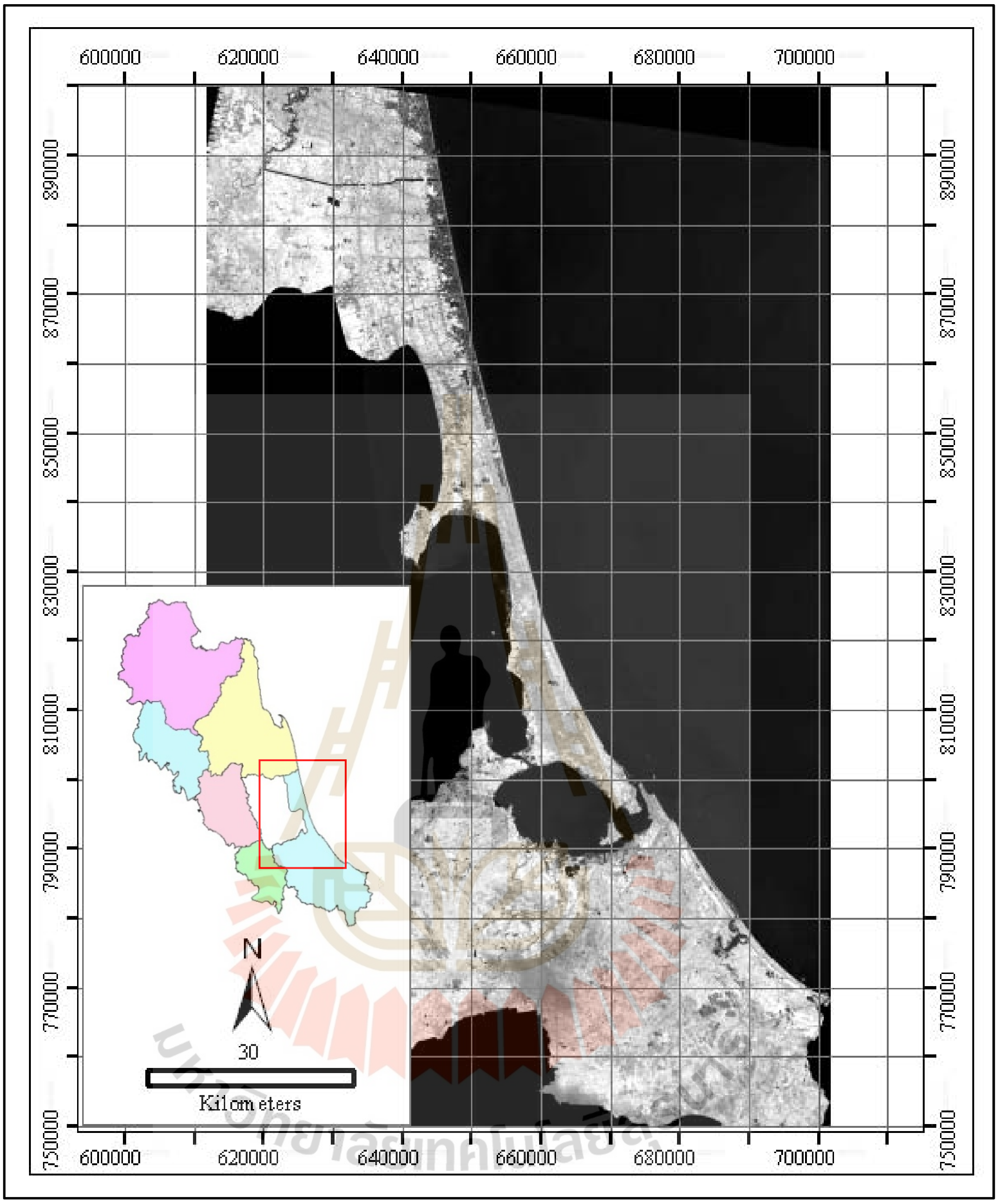

Figure 4.28 Map of Band5 divide Band 2 in Path 128 Row 55 taken on 14/09/2002 shows the result of water body.

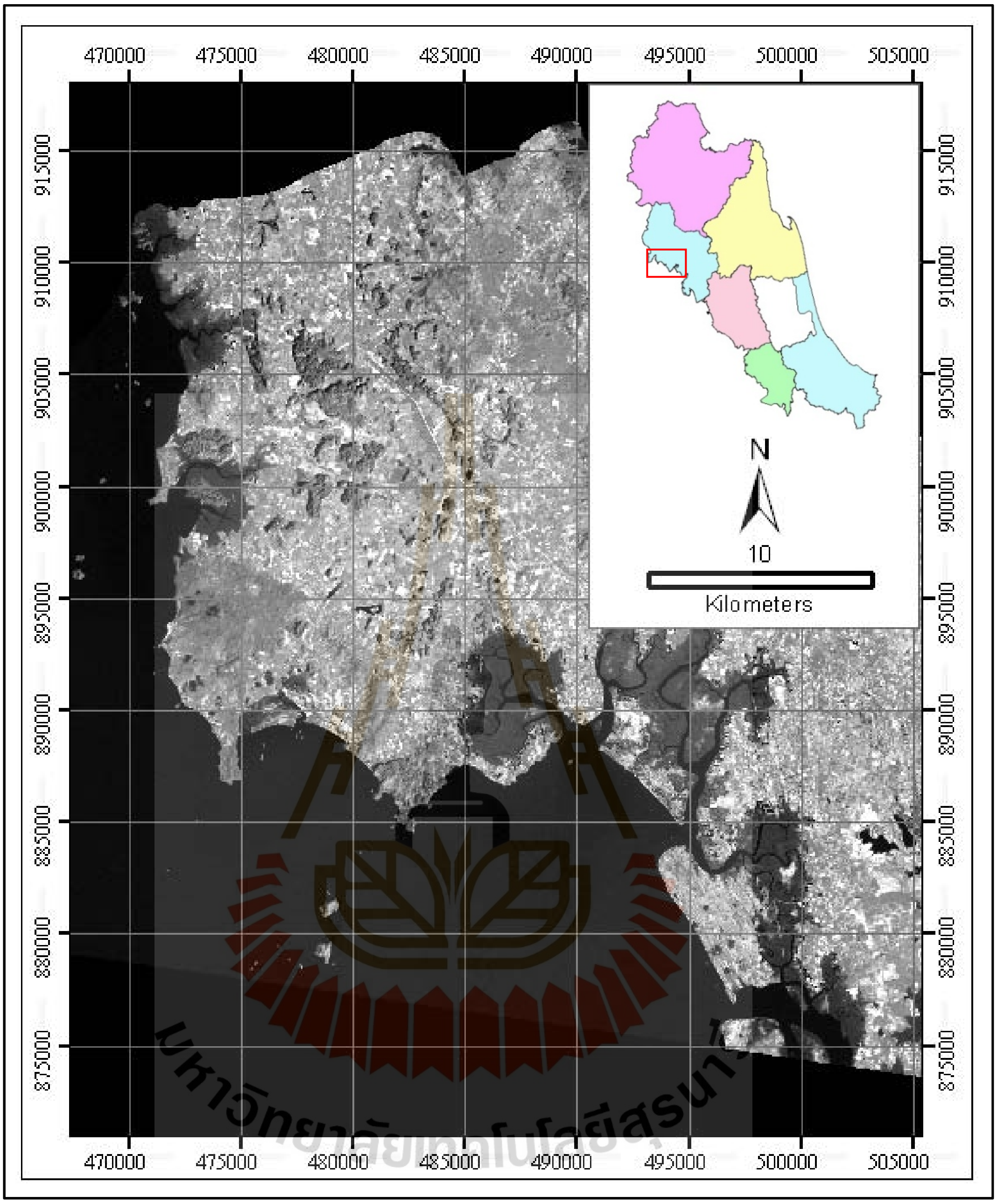

Figure 4.29 Map of Band5 divide Band 2 in Path 129 Row 54 taken on 22/02/2001 shows the result of water body.

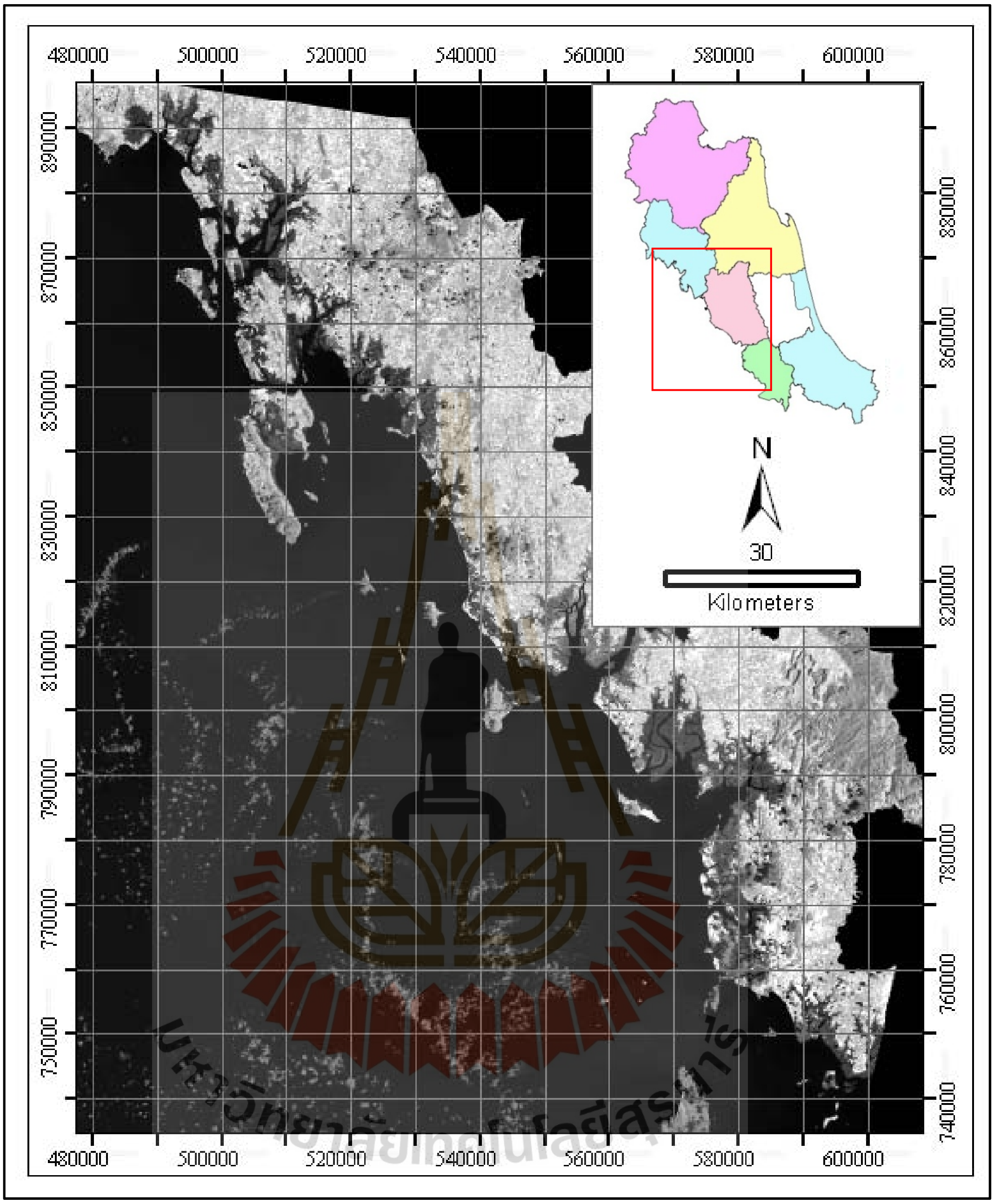

Figure 4.30 Map of Band5 divide Band 2 in Path 129 Row 55 taken on 22/02/2001 shows the result of water body.

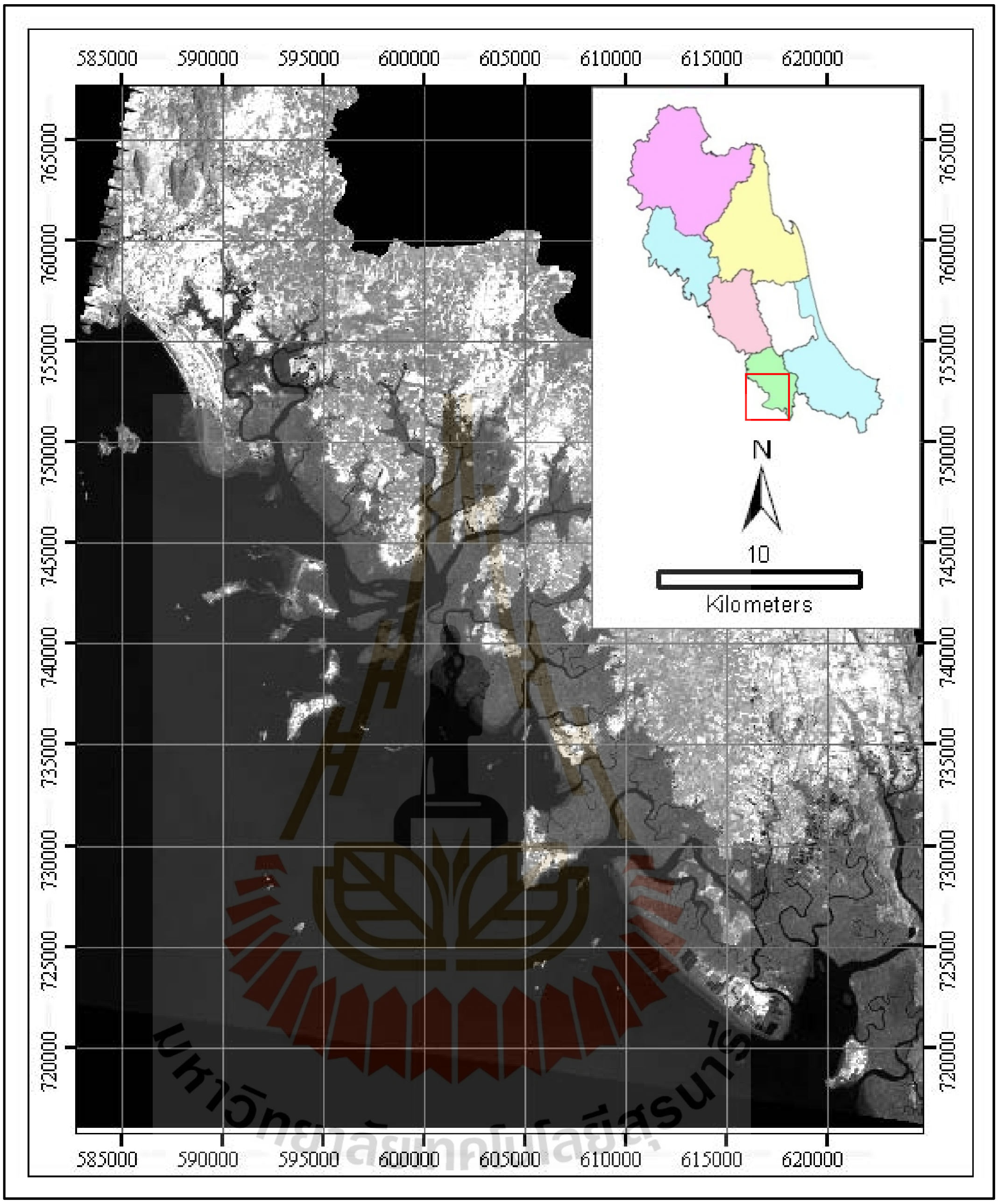

Figure 4.31 Map of Band5 divide Band 2 in Path 128 Row 55 taken on 06/03/2002 shows the result of water body.

4.2.2 The Normalized Difference Water Index

The spectral water index is a single number derived from an arithmetic operation (e.g., ratio, difference, and normalized difference) of two or more spectral bands. An appropriate threshold of the index is then established to separate water bodies from other land – cover features based on the spectral characteristics. The Normalized Difference Water Index (NDWI) is employed to reach the goal of isolating water and non – water features. There are various definitions of NDWI that combine different pairs of bands (normally of TM or ETM), typically and originally including green and near – infrared (NIR) (band 2 and band 4).

Landsat band 4 (0.75 – 0.90 µm) operates in the best spectral region to distinguish vegetation varieties and conditions. Because water is a strong absorber of NIR, this band has delineated water bodies. Since water absorbs nearly all light at this wavelength water bodies appear very dark. This contrasts with bright reflectance for soil and vegetation so it is a good band for defining the water / land interface. Landsat band 2 (0.52 – 0.60 µm) penetrates clear water fairly well and gives excellent contrast between clear and turbid (muddy) water. The normalized difference water index (NDWI) is derived using similar principles to the Normalized Difference Vegetation Index (NDVI). In an NDVI (the comparison of differences of two bands, red and NIR), the presence of terrestrial vegetation and soil features is enhanced while the presence of open water features is suppressed because of the different ways in which these features reflect these wavelengths. The NDVI index is calculated as follows: (NIR – Red) / (NIR + red). If the equation is reversed and the green band used instead of the red, then the outcome would also be reversed, the vegetation suppressed and the open water features enhanced. The equation for an NDWI is

(GREEN – NIR) / (GREEN + NIR). The selection of these wavelengths maximizes the reflectance properties of water. This is maximized the typical reflectance of water features by using green wavelengths and the minimized the low reflectance of NIR by water features. The NDWI would result the light color of water body.

The study areas cover coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea. The classification of land and water bodies using the NDWI method is shown in Figure 4.32 – 4.37. The result indicates water body is appeared lighter than the land body.

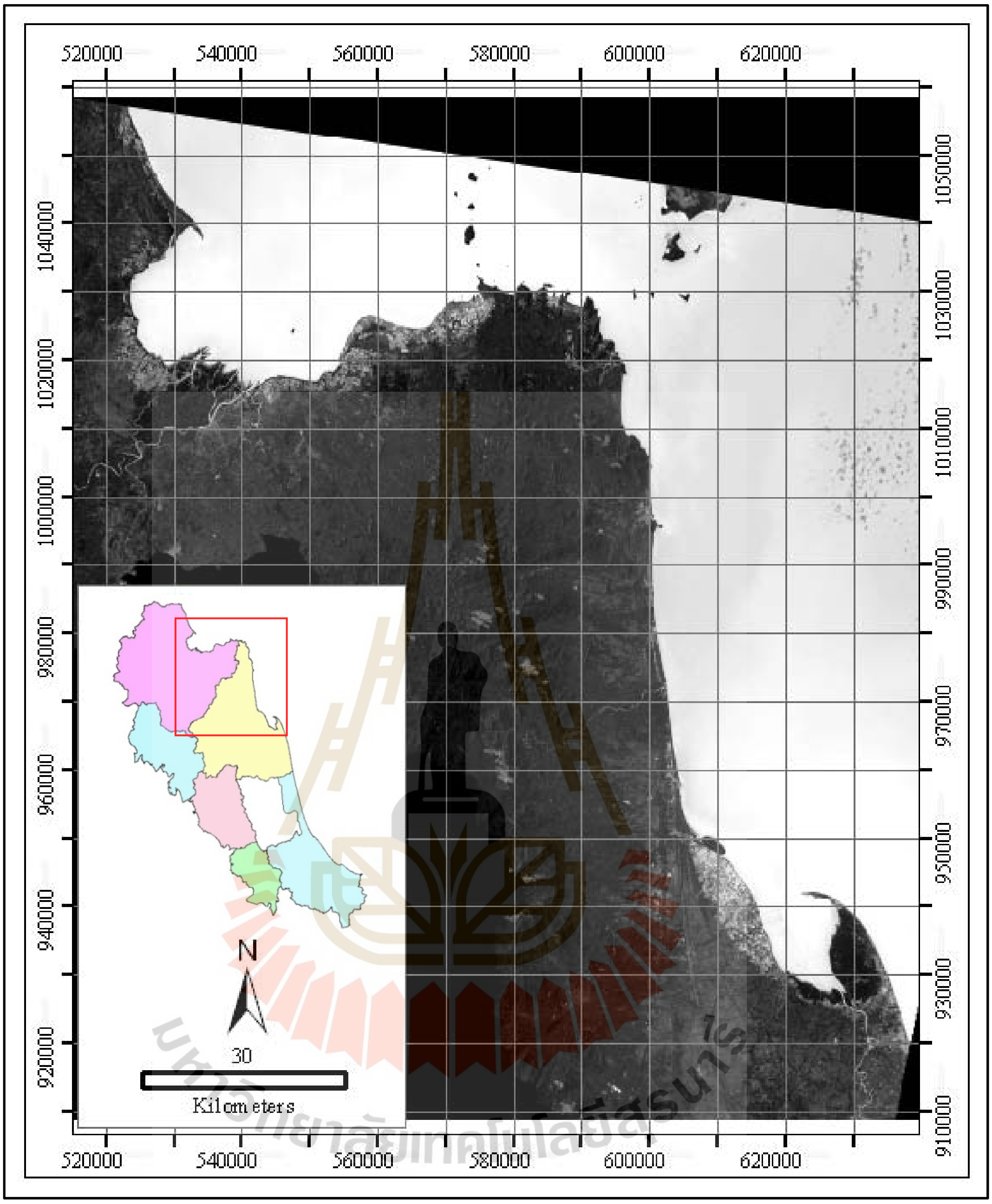

Figure 4.32 Map of NDWI in Path 129 Row 54 taken on 22/02/2001 shows the result of water body.

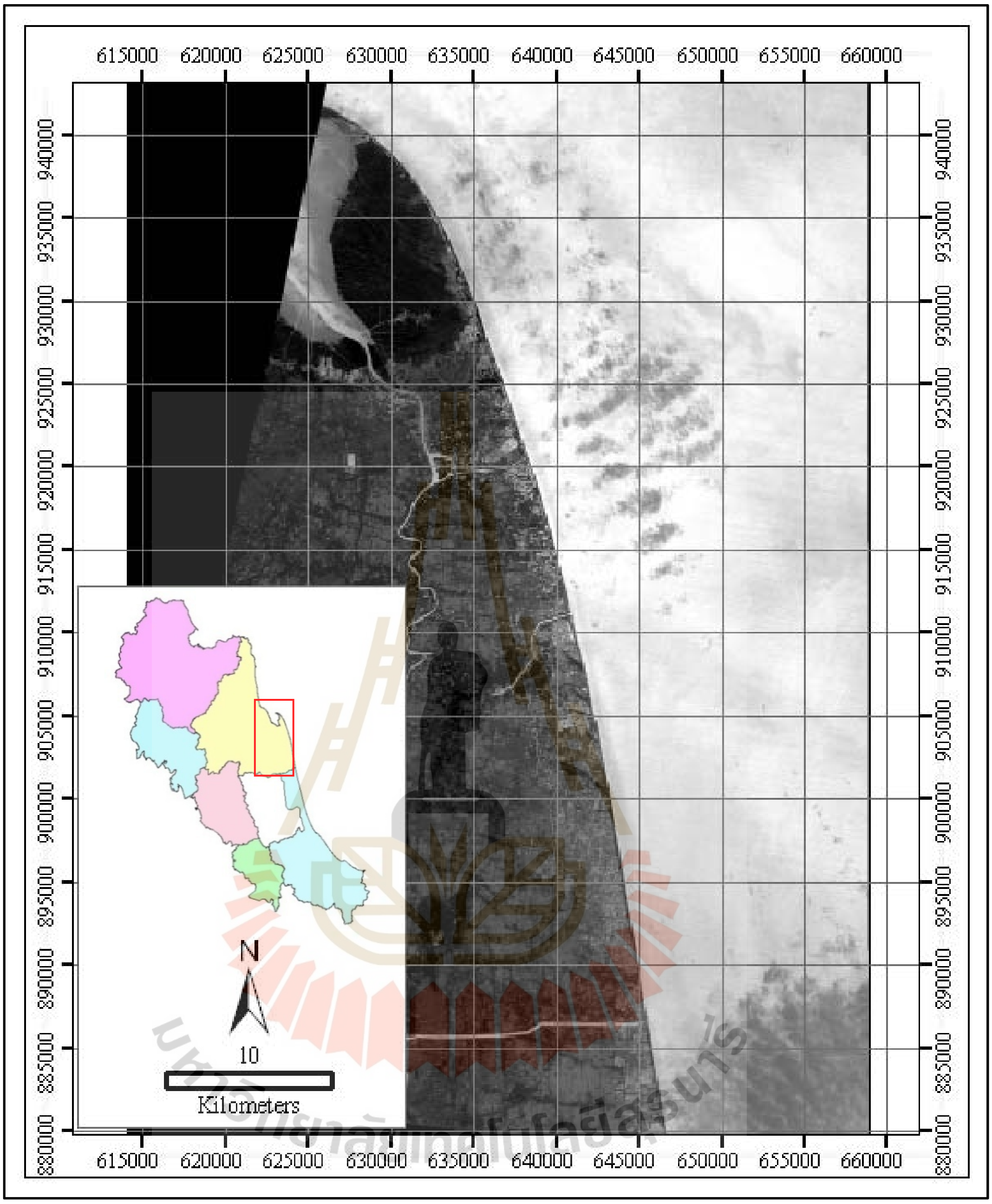

Figure 4.33 Map of NDWI in Path 128 Row 54 taken on 10/08/2004 shows the result of water body.

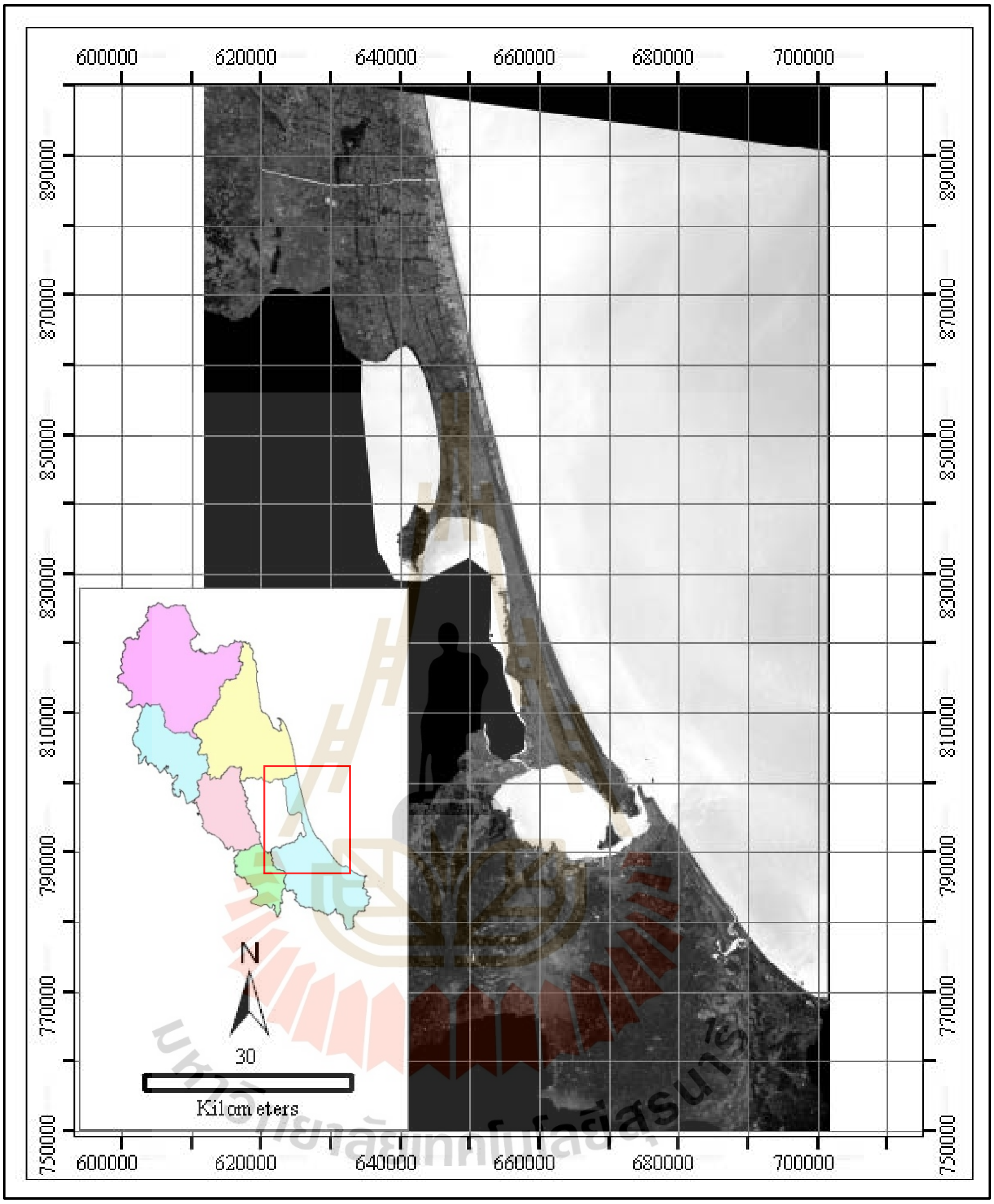

Figure 4.34 Map of NDWI in Path 128 Row 55 taken on 14/09/2002 shows the result of water body.

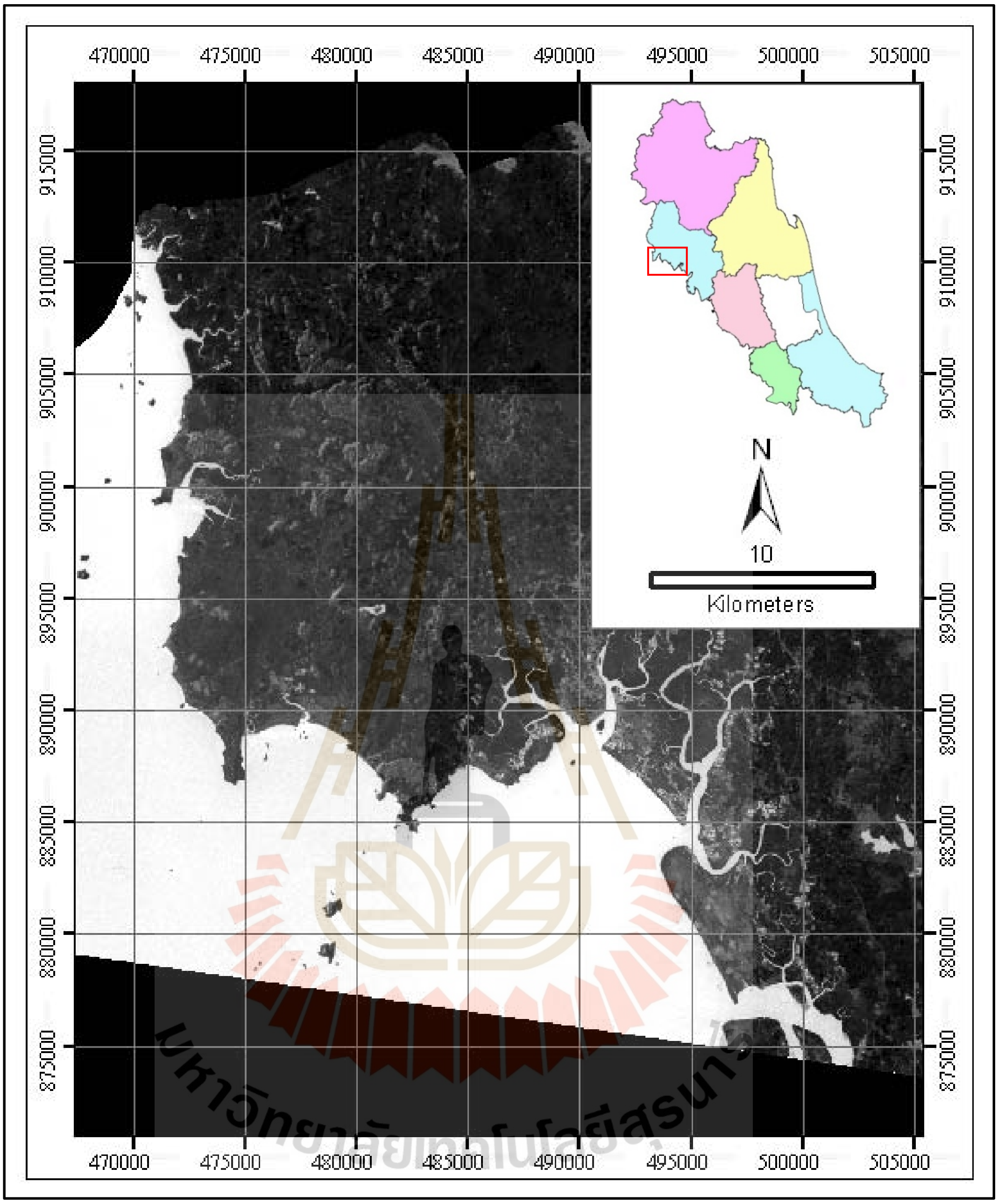

Figure 4.35 Map of NDWI in Path 129 Row 54 taken on 22/02/2001 shows the result of water body.

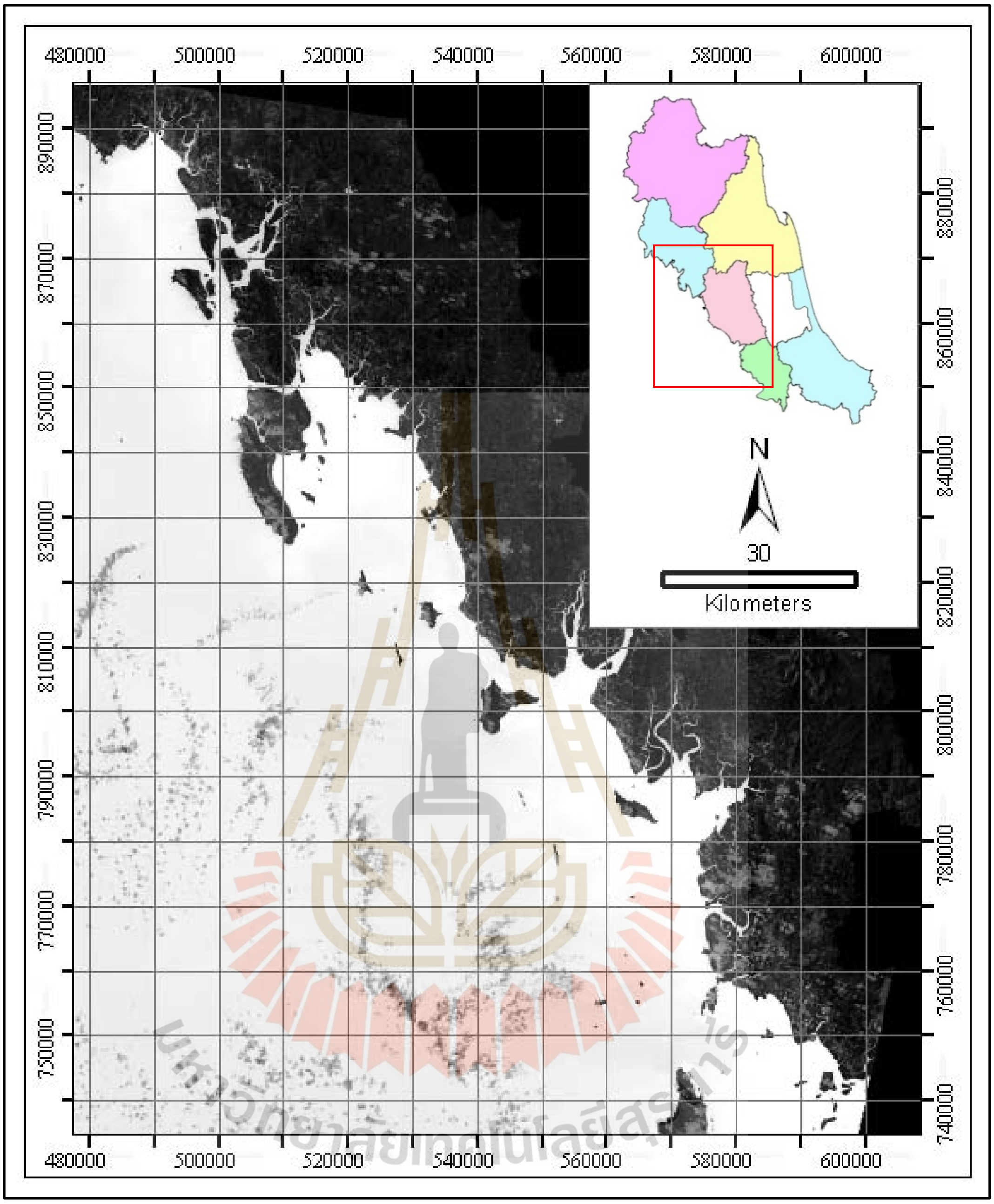

Figure 4.36 Map of NDWI in Path 129 Row 55 taken on 22/02/2001 shows the result of water body.

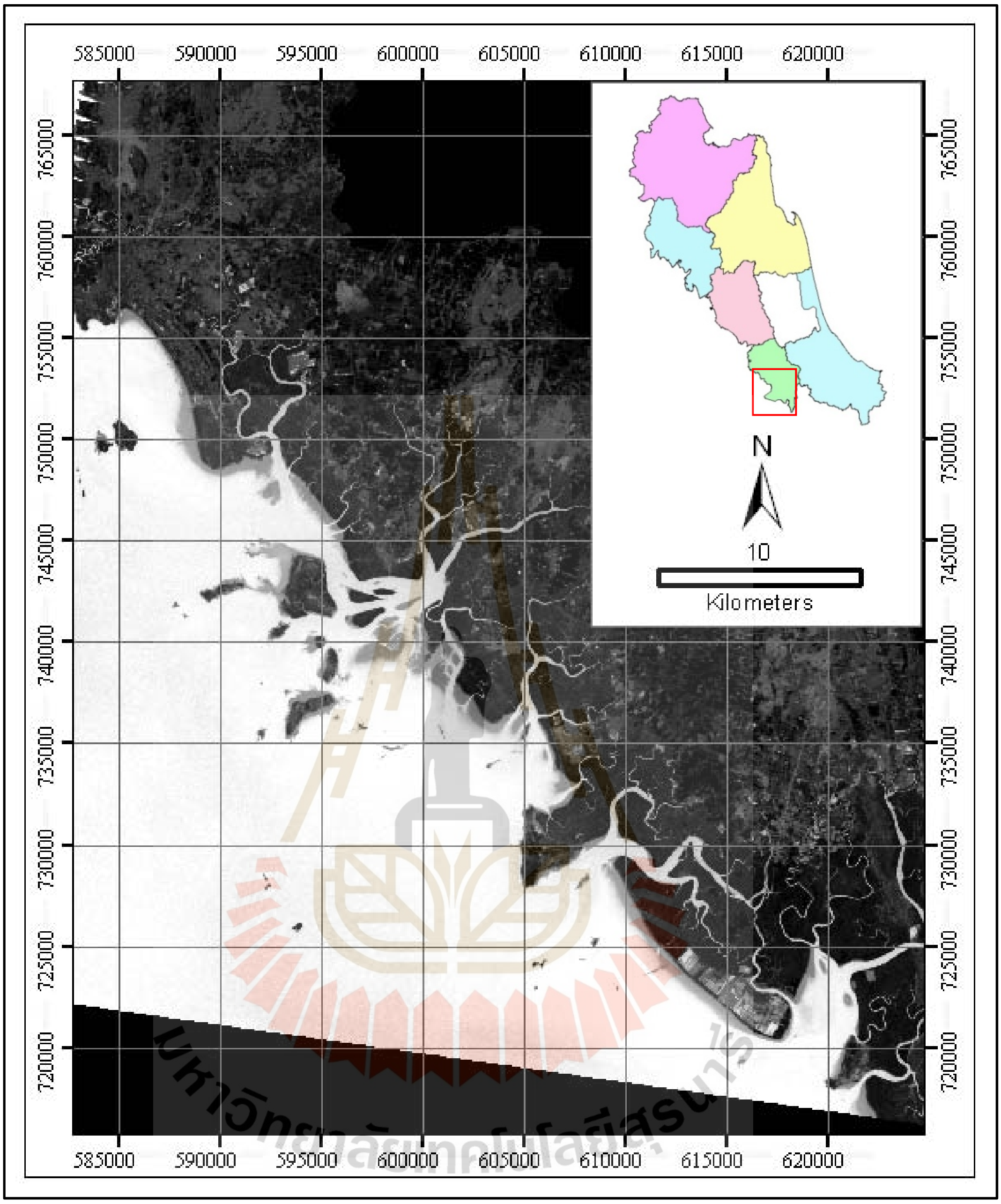

Figure 4.37 Map of NDWI in Path 128 Row 55 taken on 06/03/2002 shows the result of water body.

4.2.3 Decision Tree Classification

In this study, decision tree classification is used for classification of land and water in coastal area. This technique is performed by multistage classifications which use a series of binary decision to place pixels into classes. They must produce single band output and have a binary result of 0 or 1. The 0 is sent to the “No” branch and the 1 is sent to “Yes” branch of the decision tree. The decision tree expression can be “pruned” and edited interactively. The Normalized Difference Water Index (NDWI) equation applied in the decision tree classification is the equation 4.1. The ranges of NDWI are -1 to +1. The NDWI value is assigned to negative for the land body and the NDWI approaches positive for the water body. The best value for classification of land and water bodies in decision tree classification is 0.25 as shown in Figure 4.38.

The study areas cover coastline of Surat Thani, Nakhon Si Thammarat and Songkhla provinces in the Gulf of Thailand and of Krabi, Trang and Satun provinces in the Andaman Sea. The classification of land and water bodies using decision tree classification method is shown in Figure 4.39 – 4 .44. The result shows water body in blue color and land body in yellow color.

$$NDWI = \frac{\text{Band 2} - \text{Band 4}}{\text{Band 2} + \text{Band 4}} \tag{4.1}$$

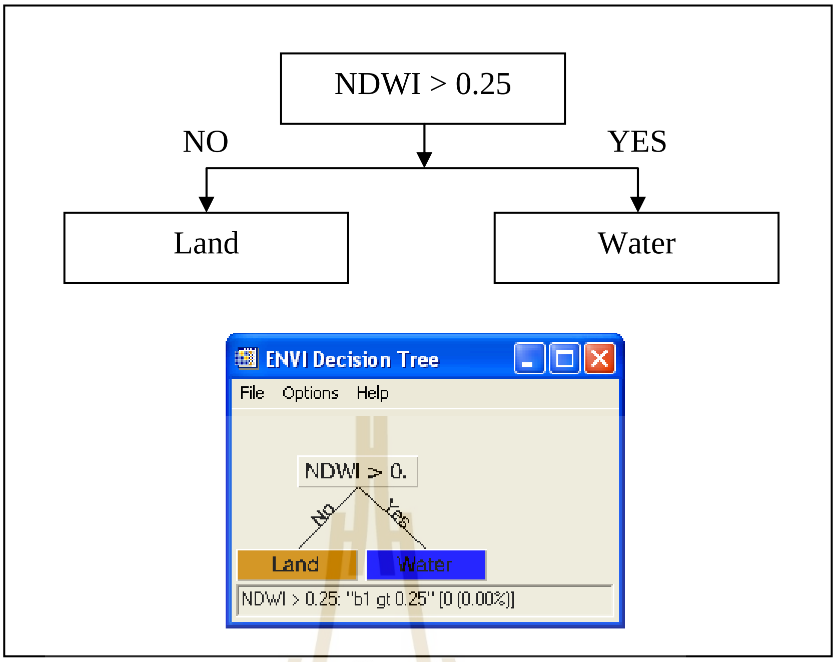

Figure 4.38 Decision Tree Classification by using NDWI

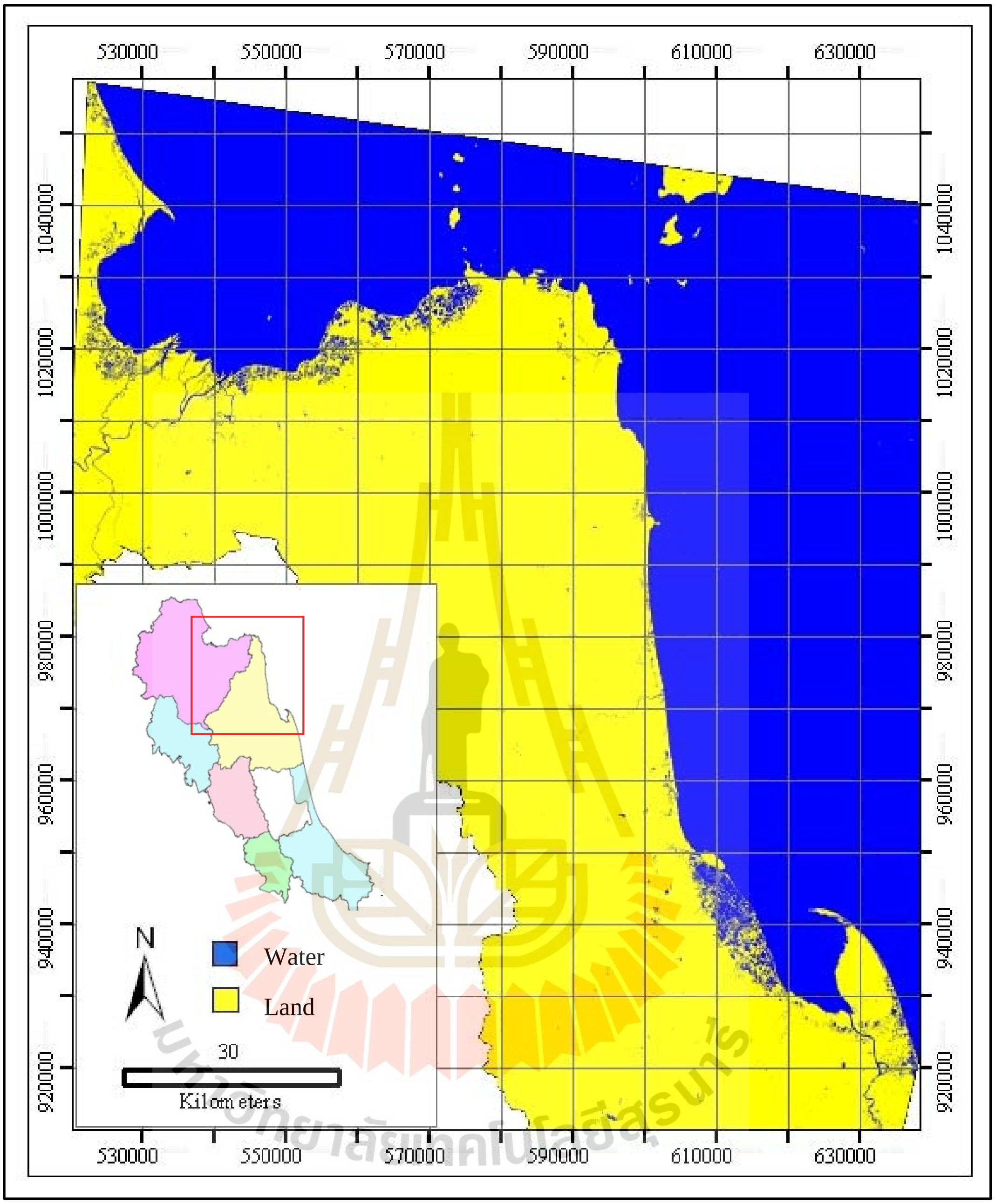

Figure 4.39 Map of NDWI classification in Path 129 Row 54 taken on 22/02/2001 shows the result of water body.

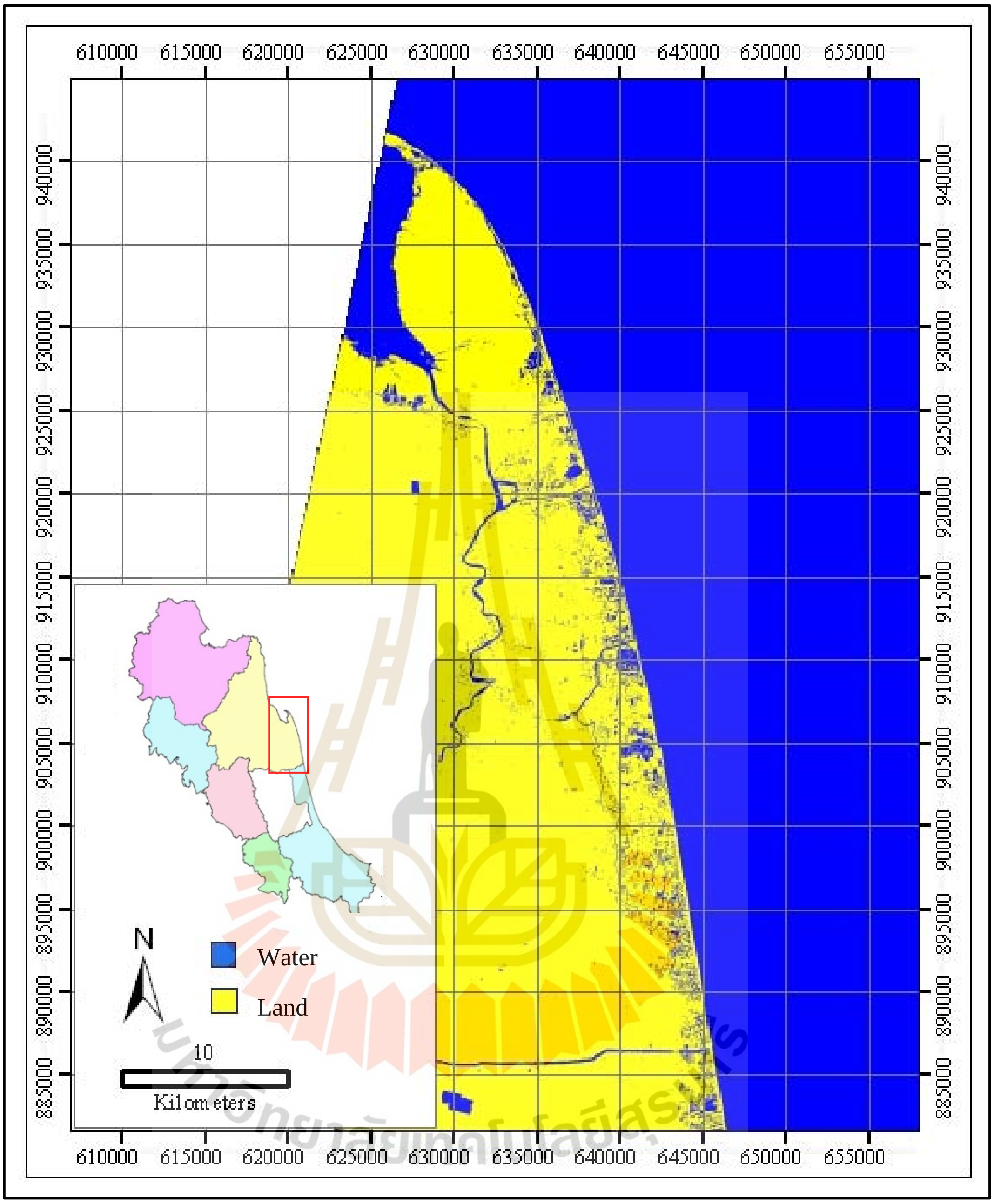

Figure 4.40 Map of NDWI classification in Path 128 Row 54 taken on 10/08/2004 shows the result of water body.

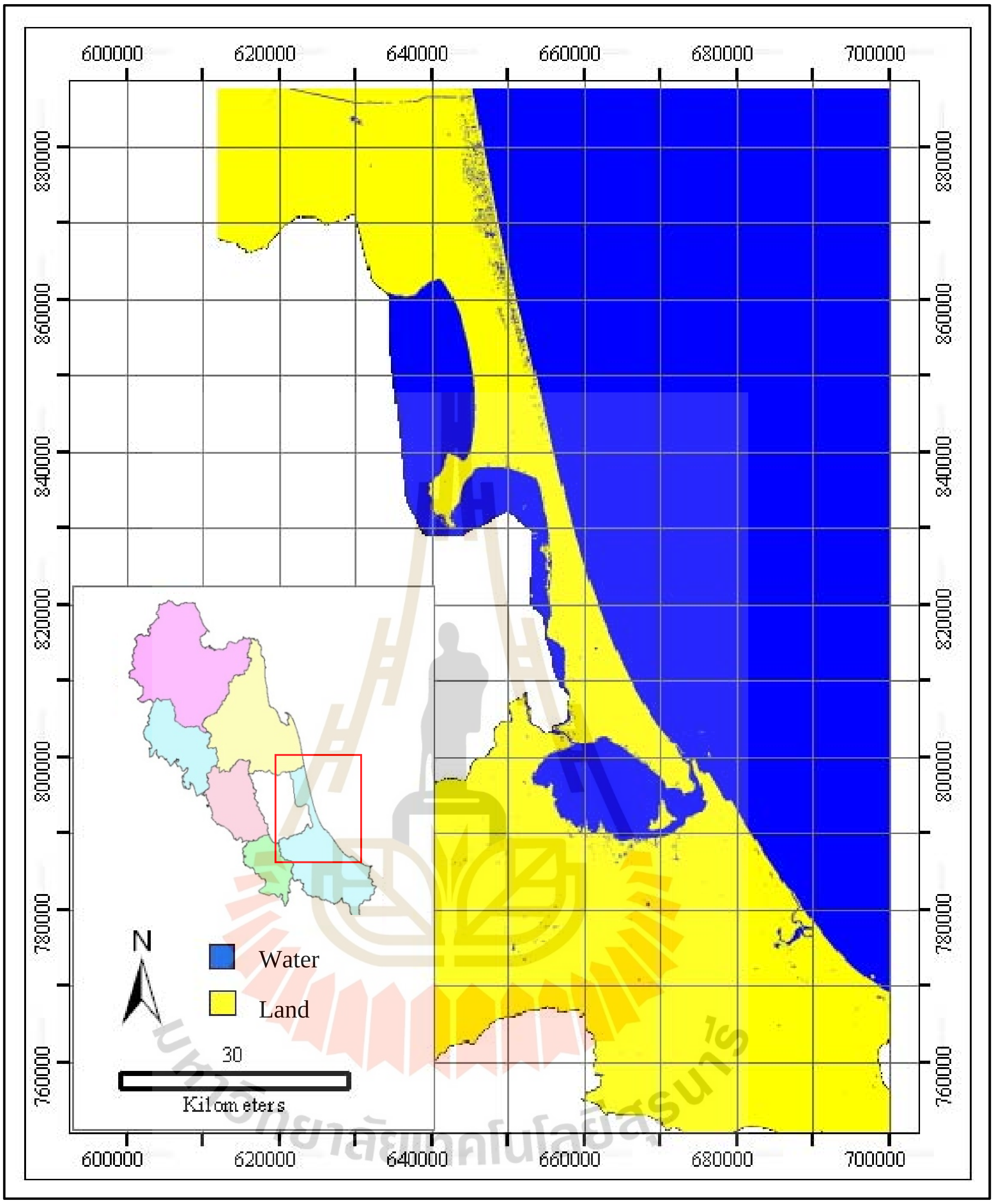

Figure 4.41 Map of NDWI classification in Path 128 Row 55 taken on 14/09/2002 shows the result of water body.

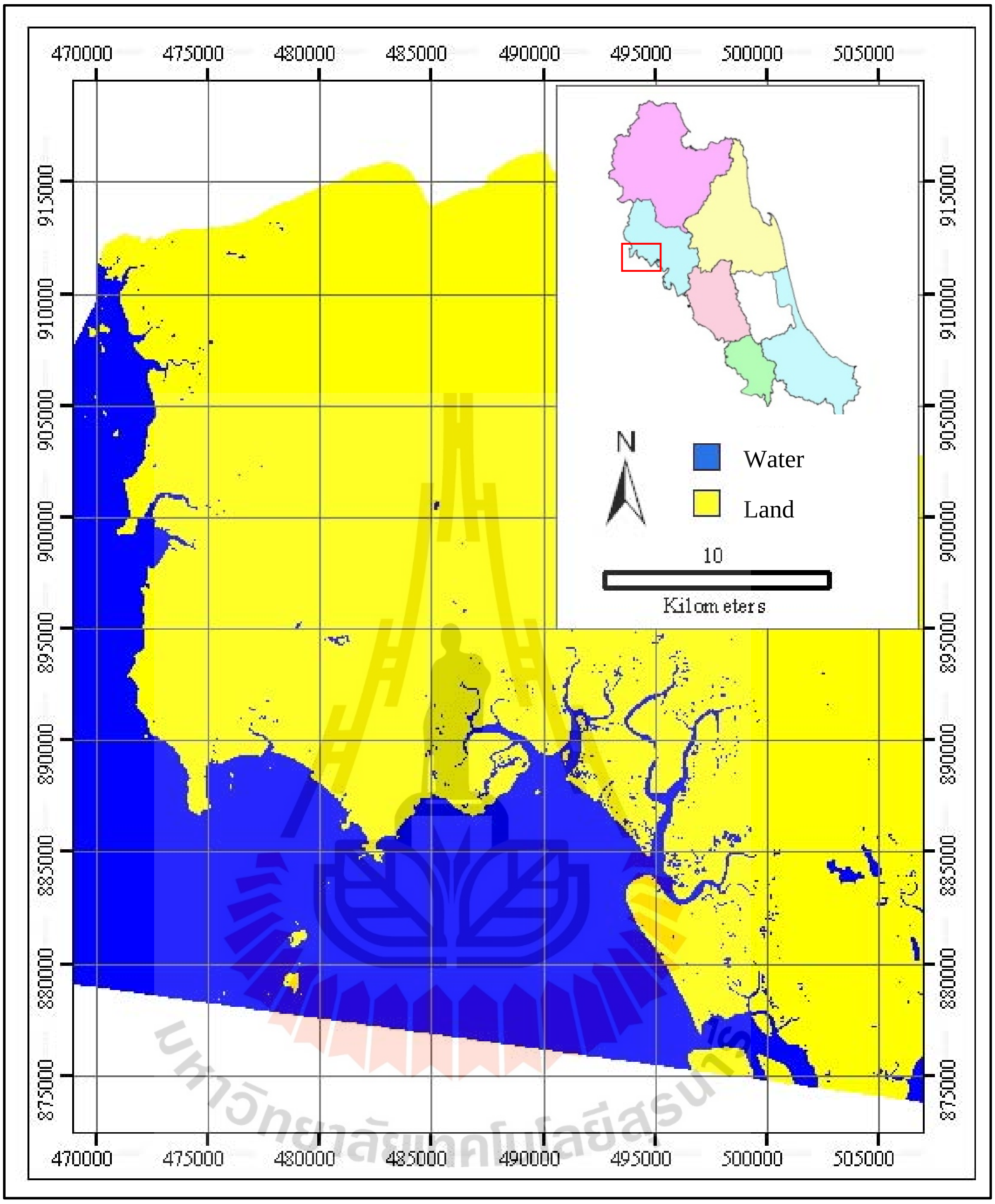

Figure 4.42 Map of NDWI classification in Path 129 Row 54 taken on 22/02/2001 shows the result of water body.

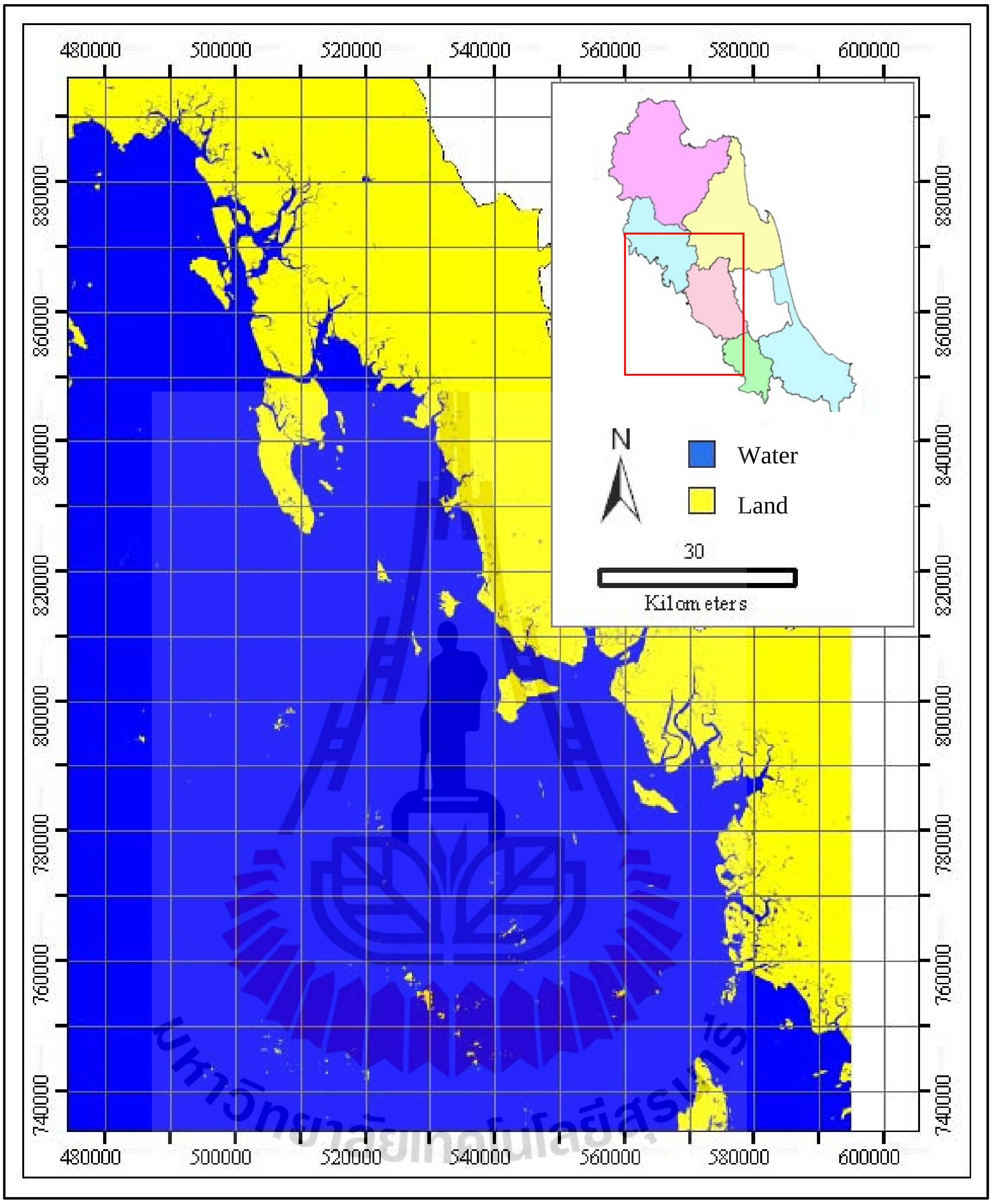

Figure 4.43 Map of NDWI classification in Path 129 Row 55 taken on 22/02/2001 shows the result of water body.

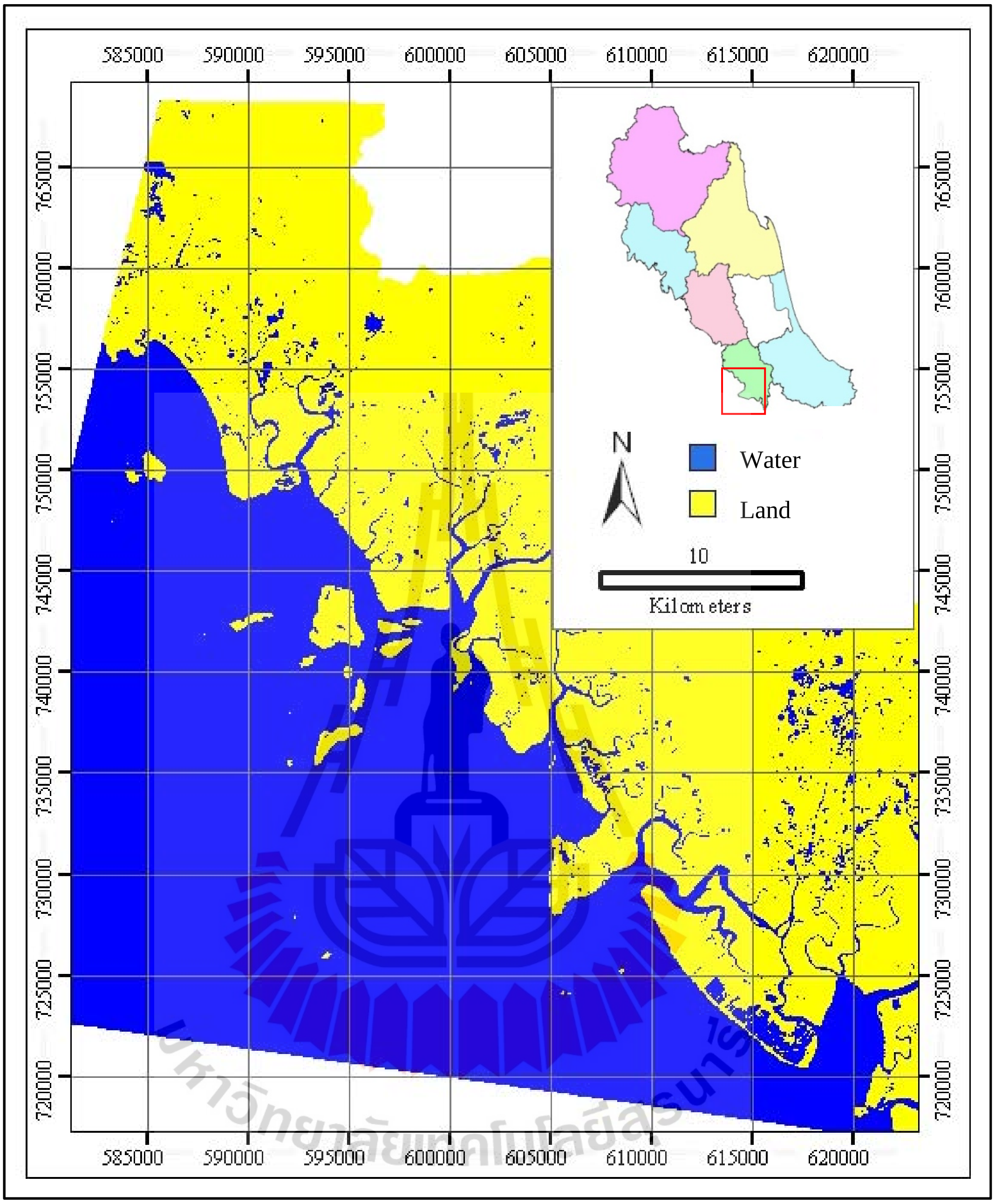

Figure 4.44 Map of NDWI classification in Path 128 Row 55 taken on 06/03/2002 shows the result of water body.

4.3 Coastline Change Detection

Many kinds of satellite data have been used in Thailand to detect the coastline change and the causes of the change. The coastal change can be distinguished by overlaying the coastline maps of in different time. The distance of coastline change is calculated by using an ArcGIS tool that compares the old and the present coastlines. Figure 4.45 shows the old coastline in green and the new coastline in purple. The coastal change between the two periods is represented by coastal erosion in red and coastal deposition in blue.

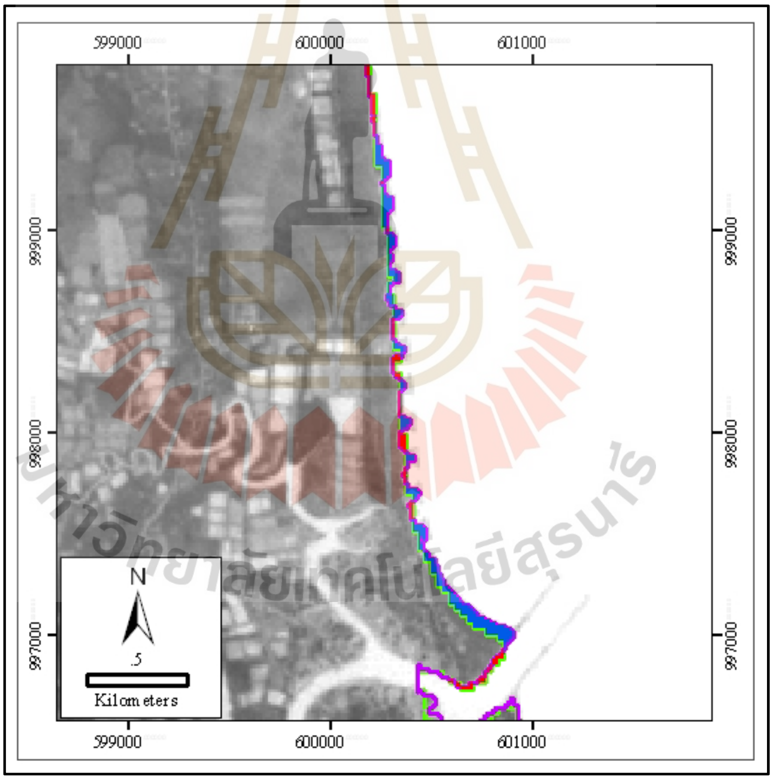

Figure 4.45 Coastline map analysis

The coastal change consisting of coastal erosion or deposition can be acquired from overlay of satellite image in different time. The rate of coastal change is calculated from the ratio of coastline width and time period (Equation 4.2), and the coastline width is obtained by ratio of coastal change area and coastline distance (Equation 4.3). Results of the rate of coastal change can be classified as shown Table 4.1.

$$\text{Rate of coastal change (m/y)} = \frac{\text{Coastline width (m)}}{\text{Time period (year)}} \qquad (4.2)$$

$$\text{Coastline width (m)} = \frac{\text{Coastal change area (m}^2\text{)}}{\text{Coastline distance (m)}} \qquad (4.3)$$

Table 4.1 Classification of the rate of coastal change. (Sinsakul et al, 2003)

Coastal Features	Rate of coastal change (m/y)
Severe erosion coast	> 5
Moderate erosion coast	1 – 5
Depositional coast	1 – 5
Stable coast	± 1

The coastal change in Thailand coast is divided into 4 classes (Sinsakul et al, 2003) as follow: 1). Severe erosion coast indicates coastal erosion more than 5 meters per year. 2). Moderate erosion coast indicates coastal erosion about 1 – 5 meters per year. The erosional coast is the weathering away of land or the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage. The rate of erosion is considered by physical change or land lost and impact to environmental and ecosystem. 3). Depositional coast is the process of material moved up the beach by the swash at an angle which is controlled by the prevailing wind. Rate of deposit is about 1 – 5 meters per year. 4). Stable coast is a balance between sediment supply, subsidence, and coastal processes. Rate of coastal change is about ± 1 meter per year.

4.3.1 Gulf of Thailand Sea Coast

The study area in the Gulf of Thailand coast consists of Surat Thani, Nakhon Si Thammarat and Songkhla provinces.

Surat Thani province comprises extensive coastline totaling about 135 kilometers in length. It covers Tha Chana, Chiya, Tha Chang, Muang, Kanchanadit and Donsak districts. The result of the study shows a few coastal changes because the area is mainly tidal flat and mangrove swamp. That coastal change is slower than sandy beach. In this province, the coastal change is found mainly in Donsak area.

Nakhon Si Thammarat province has a coastline about 190 kilometers. It's covering the Khanom, Sichon, Tha Sala, Muang, Pak Panang and Hua Sai districts. In this area the coastal change is severe because it is along monsoon and typhoon path and is relatively low area covered by mainly unconsolidated sediments. The coastal erosion is severe and affected more than 60 kilometers long. The main coastal erosion area covers the Sichon, ThaSala, Pak Panang, and Hua Sai districts

Songkhla province comprises extensive coastline totaling about 150 kilometers in length. It is covering the Ranot, Sathing Phra, Singhanakhon, Muang, Chana, and Thepha districts. The prominent coastal erosion has occurred in the northern part of Ronot district.

The study areas of the Surat Thani coast cover Ban Phot. The Nakhon Si Thammarat coast comprises the areas of Ban Fai Tha, Ban Ro and Ban Thang Khuen, Ban Tha Sung Bon, Ban Laem Talumphuk, Ban chai Thale, Ban Ao Bon, Ban Na Saton, and Ban Na San. The Songkhla coast comprises the areas of Ban Map Bua and Ban Tha Bon. The coastline maps analysis of the study areas of the Surat Thani, Nakhon Si Thammarat and Songkhla provinces is described in the following.

4.3.1.1 Ban Phot Area

The coastline of the Ban Phot area located in the Don Sak district of Surat Thani province is about 9 kilometers in length and between WGS84 UTM 1024000 to 1026500 North and UTM 562000 to 568500 East. Figure A – 1 shows the coastal change between the Landsat of 23 September, 1994 and the Landsat of 22 February, 2001. The coastal erosion is about 70.32 meters in width with a rate of 10.04 meters per year. Figure A – 2 shows the coastal change between the Landsat of 22 February, 2001 and the THEOS of 21 September, 2009. The erosion is about 7.86 meters in width with a rate of 1 meter per year.

Ban Phot area is changing from the coastal mangrove area to the shrimp ponds. The shrimp ponds are destroyed and the local road is lacking by coastal erosion (Figure A – 3). The building of the seawall in Ban Phot area in 2000, the area has been protected (Figure A – 4).

4.3.1.2 Ban Fai Tha Area

The coastline of the Ban Fai Tha area located in the Sichon district of Nakhon Si Thammarat province is about 6 kilometers in length and between WGS84 UTM 996000 to 1022000 North and UTM 599000 to 601000 East. It lies north – southerly along Ao Thung Sai to Pak Nam Sichon spits. Figure A – 5 shows the coastal change between the Landsat of 23 September, 1994 and the Landsat of 22 February, 2001. The coastal erosion is about 16.70 meters in width with a rate of 2.38 meters per year and the coastal deposition is about 7.58 meters in width with a rate of 1.08 meters per year. Figure A – 6 shows the coastal change between the Landsat of 22 February, 2001 and the THEOS of 31 July, 2009. The erosion is about 10.55 meters in width with a rate of 1.32 meters per year and the deposition is about 10.20 meters in width with a rate of 1.27 meters per year.

The coastline was formerly eroded especially by the monsoon. But since the building of the breakwaters and jetties in Pak Nam Sichon in 1999 (Figure A – 7 A), the area has been deposited by sediments (Figure A – 7 B). However, the erosion of the northern part of the area is increasing as the sediments have been transported and deposited in the southern part.

4.3.1.3 Ban Ro and Ban Thang Khuen

The coastline of the Ban Ro and Ban Thang Khuen area located in the Thasala district of Nakhon Si Thammarat province is about 7 kilometers in length and between WGS84 UTM 961500 to 968000 North and UTM 602000 to 604000 East. It lies north – southerly along the local road. Figure A – 8 shows the coastal change between the Landsat of 23 September, 1994 and the Landsat of 22 February, 2001. The coastal erosion is about 13.62 meters in width with a rate of 1.95 meters per year. Figure A – 9 shows the coastal change between the Landsat of 22 February, 2001 and the THEOS of 31 July, 2009. The coastal erosion is about 10 meters in width with a rate of 1.25 meters per year and the coastal deposition is about 1.02 meters in width with a rate of 0.13 meters per year.

The coastal erosion is mostly in the sandy beach. The change observed between two periods of 29 January, 2011 and 17 July, 2012shows the collapsed house at Ban Ro area (Figure A – 10) and the uprooted trees at Wat Thang Khuen area (Figure A – 11).

4.3.1.4 Ban Tha Sung Bon

The coastline of the Ban Tha Sung Bon area located in the center of Thasala district of Nakhon Si Thammarat province is about 7.5 kilometers in length and between WGS84 UTM 955000 to 961500 North and UTM 603000 to 605000 East. Figure A – 12 shows the coastal change between the Landsat of 23 September, 1994 and the Landsat of 22 February, 2001. The coastal erosion is about 13.86 meters in width with a rate of 1.98 meters per year and the coastal deposition is about 8.75 meters in width with a rate of 1.25 meters per year. Figure A – 13 shows the coastal change between the Landsat of 22 February, 2001 and the THEOS of 31 July, 2009. The coastal erosion is about 4.11 meters in width with a rate of 0.51 meters per year and the coastal deposition is about 18.37 meters in width with a rate of 2.29 meters per year.

This area is a narrow sandy beach covering with many shrimp ponds. It has been deposited by sediments since the building of the jetties, breakwaters, and groins in Ban Tha Sung Bon and Hat Dan Phasi in 1997 (Figure A – 14A). The northern part is eroded in the monsoon season. The channel in the Ban Nai Thung is blocked by the sediment deposition (Figure A – 14B).

4.3.1.5 Ban LaemTalumphuk

The coastline of the Ban Laem Talumphuk area located in the Pak Panang district of Nakhon Si Thammarat province is about 11.42 kilometers in length and between WGS 84 UTM 934500 to 941000 North and UTM 627500 to 633000 East. Figure A – 15 shows the coastal change between the Landsat of 20 February, 1994 and the Landsat of 10 August, 2004. The coastal erosion is about 13.66 meters wide and is at the rate of 1.37 meters per year. Figure A – 16 shows the coastal change between the Landsat of 10 August, 2004 and the SPOT of 16 March, 2007. The coastal erosion is about 13.45 meters wide and is at the higher rate of 4.48 meters per year.

The area is about 1 meter above mean sea level and comprises spit and sandy beach. It consists of unconsolidated sediments. The land use has been changed from the coastal mangrove to the shrimp ponds which are now destroyed by the coastal erosion (Figure A – 17).

4.3.1.6 Ban Chai Thale

The coastline of the Ban Chai Thale area located in the Pak Panang district of Nakhon Si Thammarat province is about 9 kilometers in length and between WGS 84 UTM 924500 to 931000 North and UTM 634000 to 637500 East. Figure A – 18 shows the coastal change between the Landsat of 20 February, 1994 and the Landsat of 10 August, 2004. The coastal erosion is about 11.72 meters in width with the rate of 1.17 meters per year. Figure A – 19 shows the coastal change between the Landsat of 10 August, 2004 and the SPOT of 16 March, 2007. The erosion is about 14.23 meters in width with the rate of 4.74 meters per year.

Ban Chai Thale area is consists of many shrimp ponds distributed in the narrow sandy beach. Figure A – 20 shows the collapsed house destroyed by the erosion.

4.3.1.7 Ban Ao Bon

The coastline of the Ban Ao Bon area located in the Pak Panang district of Nakhon Si Thammarat province is about 8 kilometers in length and between WGS 84 UTM 912000 to 918000 North and UTM 638500 to 641000 East. Figure A – 21 shows the coastal change between the Landsat of 20 February, 1994 and the Landsat of 10 August, 2004. The coastal erosion is about 21.25 meters wide with the rate of 2.13 meters per year. Figure A – 22 shows the coastal change between the Landsat of 10 August, 2004 and the SPOT of 16 March, 2007. The coastal erosion is about 26.37 meters in width with the rate of 8.79 meters per year.

The coastline of the Ban Ao Bon area is consists of many shrimp ponds distributed in the narrow sandy beach. The main road is sensitive to destruction by the coastal erosion. This area has been eroded more than 5 meters per year. Figure A – 23 show the collapsed house destroyed by the erosion.

4.3.1.8 Ban Na Saton

The coastline of the Ban Na Saton area located in the Hua Sai district of Nakhon Si Thammarat province is about 7 kilometers in length and between WGS 84 UTM 893000 to 899000 North and UTM 643000 to 645000 East. Figure A – 24 shows the coastal change between the Landsat of 20 February, 1994 and the Landsat of 10 August, 2004. The coastal erosion is about 11.08 meters wide and is at the rate of 1.12 meters per year. Figure A – 25 shows the coastal change between the Landsat of 10 August, 2004 and the THEOS of 10 July, 2009. The coastal erosion is about 6.52 meters wide with the rate of 1.30 meters per year and the coastal deposition is about 7.29 meters in width with the rate of 1.46 meters per year.

The main road is in the narrow sandy beach, which lies north – southerly. There are many shrimp ponds distributed along the coast. The building of the seawall and 23 breakwaters in 2004 for coastal protection (Figure A – 26), the area has increased the sediment deposition. However, the erosion of the northern part of the area has also been increased as no breakwater existed.

4.3.1.9 Ban Na San

The coastline of the Ban Na Saton area located in the Hua Sai district, Nakhon Si Thammarat province is about 7 kilometers in length and between WGS 84 UTM 887000 to 893000 North and UTM 644000 to 646000 East. Figure A – 27 shows the coastal change between the Landsat of 20 February, 1994 and the Landsat of 10 August, 2004. The erosion is about 28.55 meters in wide and is at the rate of 2.85 meters per year. Figure A – 28 shows the coastal change between the Landsat of 10 August, 2004 and the THEOS of 10 July, 2009. The coastal erosion is about 8.64 meters in wide with the rate of 1.73 meters per year and the coastal deposition is about 2.04 meters in wide with the rate of 0.41 meters per year.

The Ban Na San area is located south of the Ban Na Saton area and shows similar condition. The pier and seawall of Ban Na San were destroyed by wave and wind in the monsoon season (Figure A – 29). The sediments have been deposited in the southern part of the breakwaters (Figure A – 30).

4.3.1.10 Ban Map Bua

The coastline of the Ban Map Bua area located in the Ranod district, Songkhla province is about 7.3 kilometers in length and between WGS 84

UTM 868500 to 874500 North and UTM 647500 to 649500 East. Figure A – 31 shows the coastal change between the Landsat of 1 June, 1990 and the Landsat of 14 September, 2002. The coastal erosion is about 7.23 meters in width and is at the rate of 0.60 meters per year. Figure A – 32 shows the coastal change between the Landsat of 14 September, 2002 and the THEOS of 10 July, 2009. The coastal erosion is about 10.79 meters in width with a rate of 1.54 meters per year.

Ban Map Bua area is many shrimp ponds distributed along the narrow sandy beach. The village is on the outside of the beach, which is sensitive to coastal erosion. The building of the seawall in Ban Map Bua pier the area has been protected. However the tilting tree and tree root loosen due to coastal erosion (Figure A – 33).

4.3.1.11 Ban Tha Bon

The coastline of the Ban Tha Bon area located in the Ranod district, Songkhla province is about 7.5 kilometers in length and between WGS 84 UTM 861000 to 867500 North and UTM 649000 to 651000 East. Figure A – 34 shows the coastal change between the Landsat of 1 June, 1990 and the Landsat of 14 September, 2002. The coastal erosion is about 14.34 meters in width with the rate of 1.19 meters per year. Figure A – 35 shows the coastal change between the Landsat of 14 September, 2002 and the THEOS of 10 July, 2009. The erosion is about 13.50 meters in width with a rate of 1.93 meters per year.

Ban Tha Bon area is consists of many shrimp ponds distributed in the narrow sandy beach. The village is sensitive to erosion because it's on the outside of the beach. Figure A – 36 shows the uprooted trees by erosion.

4.3.2 Andaman Sea Coast

The study area is situated in the southern part of Thailand. It is located in the Krabi, Trang and Satun provinces of the Andaman Sea coast.

Krabi province comprises extensive coastline totaling about 160 kilometers in length. It's covering Ao Luek, Muang Krabi, Nuea Khlong, and Khlong Thom districts. This coastal is mainly intertidal flat and mangrove swamp. The sandy beach is narrow and sensitive to coastal erosion. The main coastal erosion area covers the Muang Krabi district.

The coast of Trang province is about 150 kilometers in length and it lies within the Sikoa, Kantang, Hat Samran, and Palian districts. This coastal is intertidal flat, mangrove swamp and narrow sandy beach. The prominent coastal erosion has occurred in the Sikao district.

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

The coastline maps analysis of the study areas of the Krabi, Trang and Satun provinces is described in the following. The study area of the Krabi is Ban Laem Pho. The Trang coast comprises the areas of Hat Ratcha Mongkhon and Ban Pak Meng. The Satun coast comprises the areas of Ban Thung Sabo and Ban Ravi and Ban Pak La Ngu.

4.3.2.1 Ban Laem Pho

The coastline of the Ban Laem Pho area located in the Muang district of Krabi province is about 8 kilometers in length and e between WGS 84

UTM 886000 to 890000 North and UTM 484500 to 490000 East. Figure B – 1 shows the coastal change between the Landsat of 5 February, 1989 and the Landsat of 22 February, 2001. The coastal erosion is about 15.88 meters in width with the rate of 1.32 meters per year.

Study area located from Ao Nam Mao to Ban Laem Pho. The coastal erosion is mainly in Laem Pho Shell Cemetery that is important of travelling. This place is in Quaternary Period about 40 – 50 ma that is layers of Gastropod inter – bedded shale. Figure B – 2 shows the broken shell bed by erosion.

4.3.2.2 Hat Ratcha Mongkhon

The coastline of the Hat Ratcha Mongkhon area located in the Sikao district, Trang province is about 7.7 kilometers in length and between WGS 84 UTM 828000 to 835000 North and UTM 531000 to 537000 East. Figure B – 3 shows the coastal change between the Landsat of 5 February, 1989 and the Landsat of 22 February, 2001. The coastal erosion is about 23.01 meters in wide and at the rate of 1.92 meters per year.

Hat Ratcha Mongkhon is located in the Rajamangala University of Technology Srivijaya of the Trang campus. Figure B – 4 show the big pines are uprooted by the erosion.

4.3.2.3 Ban Pak Meng

The coastline of the Ban Pak Meng area located in the Sikao district, Trang province is about 9 kilometers in length and between WGS84 UTM 823000 to 829000 North and UTM 535000 to 538000 East. Figure B – 5 shows the coastal change between the Landsat of 5 February, 1989 and the Landsat of 22 February, 2001. The coastal erosion is about 20.42 meters in wide with the rate of

1.70 meters per year. Figure B – 6 shows the coastal change between the Landsat of 22 February, 2001 and the SPOT of 12 March, 2006. The coastal erosion is about 5.20 meters wide and is at the rate of 1.04 meters per year and the coastal deposition is about 7.27 meters wide with the rate of 1.45 meters per year.

The coastal erosion is mainly occurred in the Hat Pak Meng of the Hat Chao Mai National Park. The area is a sandy beach with the fallen trees left by the coastal erosion. The small breakwater using bamboos and sand bags was also built as shown in Figure B – 7. In 1995, the seawall was built to protect the area from the coastal erosion but some part the seawall was destroyed (Figure B – 8). .

4.3.2.4 Ban Thung Sabo and Ban Ravi

The coastline of the Ban Thung Sabo and Ban Ravi areas located in the Thung Wa district of Satun province is about 7 kilometers in length and between WGS 84 UTM 771000 to 777500 North and UTM 573000 to 576000 East. Figure B – 9 shows the coastal change between the Landsat of 5 February, 1989 and the Landsat of 22 February, 2001. The coastal erosion is about 22.81 meters in width and is at the rate of 1.90 meters per year. Figure B – 10 shows the coastal change between the Landsat of 22 February, 2001 and the SPOT of 25 November, 2007. The erosion is about 9.15 meters in width with a rate of 1.53 meters per year.

Ban Thung Sabo and Ban Ravi area are narrow sandy beach that are sensitive to coastal erosion. Figure B – 11 shows the uprooted tree by erosion. However the building of the riprap seawall in this area, that has been protected.

4.3.2.5 Ban Pak La Ngu

The coastline of the Ban Pak La Ngu area located in the La Ngu district of Satun province is about 9 kilometers in length and between WGS 84 UTM 750000 to 756000 North and UTM 585500 to 589500 East. Figure B – 12 shows the coastal change between the Landsat of 1 June, 1990 and the Landsat of 6 March, 2002. The coastal erosion is about 44 meters in width and is at the higher rate of 3.67 meters per year. Figure B – 13 shows the coastal change between the Landsat of 6 March, 2002 and the SPOT of 28 February, 2007. The erosion is about 7.96 meters in width with a rate of 1.59 meters per year.

Ban Pak La Ngu is narrow sandy beach that is sensitive to coastal erosion. It has been protected since the building of riprap seawall. Figure B – 14 shows the uprooted trees and lacked road in the storm season.

The coastal change can be distinguished by the overlaying the coastline maps of different times and field investigation. The distance of the coastline change and the rate of change of the Gulf of Thailand and the Andaman Sea are shown in Table 4.2 and Table 4.3 respectively.

Table 4.2 Computed distance and rate of the coastal change in the Gulf of Thailand.

Area	Year		EROSION		DEPOSITION	
	Start	End	Perpendicular Distance to the Coast (m)	Rate of Coastal Change (m/yr)	Perpendicular Distance to the Coast (m)	Rate of Coastal Change (m/yr)
B Phot	1994	2001	70.32	10.04	-	-
	2001	2009	7.86	1.00	-	-
B Fai Tha	1994	2001	16.70	2.38	7.58	1.08
	2001	2009	10.55	1.32	10.20	1.27
B Ro & B. Thang Khuen	1994	2001	13.62	1.95	-	-
	2001	2009	10.00	1.25	1.02	0.13
B. Tha Sung Bon	1994	2001	13.86	1.98	8.75	1.25
	2001	2009	4.11	0.51	18.37	2.29
B LaemTalumphuk	1994	2004	13.66	1.37	-	-
	2004	2007	13.45	4.48	-	-
B Chai Thale	1994	2004	11.72	1.17	-	-
	2004	2007	14.23	4.74	-	-
B Ao Bon	1994	2004	21.25	2.13	-	-
	2004	2007	26.37	8.79	-	-
B Na Saton	1994	2004	11.08	1.12	-	-
	2004	2009	6.52	1.30	7.29	1.46
B Na San	1994	2004	28.55	2.85	-	-
	2004	2009	8.64	1.73	2.04	0.41
B Map Bua	1990	2002	7.23	0.60	-	-
	2002	2009	10.79	1.54	-	-
B Tha Bon	1990	2002	14.34	1.19	-	-
	2002	2009	13.50	1.93	-	-

Table 4.3 Computed distance and rate of the coastal change in the Andaman Sea.

Area	Year		EROSION		DEPOSITION	
	Start	End	Perpendicular Distance to the Coast (m)	Rate of Coastal Change (m/yr)	Perpendicular Distance to the Coast (m)	Rate of Coastal Change (m/yr)
B Laem Pho	1989	2001	15.88	1.32	-	-
Hat Ratcha Mongkhon	1989	2001	23.01	1.92	-	-
B Pak Meng	1989	2001	20.42	1.70	-	-
	2001	2006	5.20	1.04	7.27	1.45
B Thung Sabo & B Ravi	1989	2001	22.81	1.90	-	-
	2001	2007	9.15	1.53	-	-
B Pak La Ngu	1990	2002	44.00	3.67	-	-
	2002	2007	7.96	1.59	-	-

CHAPTER 5

DISCUSSIONS AND CONCLUSIOS

The methodology and result of coastal change of this study in the preceding chapters are discussed in this chapter. Additional discussion on further study and conclusion are also included.

5.1 Discussions

The study area is situated in the southern part of Thailand. The coastline of the Andaman Sea of Krabi, Trang and Satun provinces are 160, 150 and 168 kilometers long respectively. The coastline of the Gulf of Thailand of Surat Thani, Nakhon Si Thammarat and Songkhla provinces are 135, 190 and 150 kilometers long respectively.

Based on the available remote sensing and field data, a conceptual geomorphologic map and coastline map were produced using remote sensing and GIS techniques. The remote sensing technique of interpretation and classification provide information about the occurrences of coastal change. According to this study, it has been found that spatial satellite image merged with product of Landsat, SPOT and THEOS are quite useful for coastal change interpretation as well as geomorphologic study. The GIS has been demonstrated to be a convenient tool for sorting and displaying data, analysis and generating the coastline map and geomorphologic map.

The coastal change study can be divided into two parts, i.e., geomorphology and coastline change detection. The geomorphologic study used the image classification and field investigation. The coastline change detection was achieved by overlaying of coastline maps in different time.

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

The coastal change is detected by using remote sensing and GIS techniques, which are useful to study of wide area and in different times. The methods for studying the coastal change are the band ratio (SWIR/GREEN), the Normalized Difference Water Index (NDWI), the decision tree classification and the field investigation. The band ratio and NDWI methods would reveal the water body and the land body. The comparison of band ratio and NDWI shows that the water body observed from NDWI is more distinct than the band ratio and is appeared as light color. The NDWI value is applied to use in decision tree classification and the best value for classification of land and water bodies is 0.25. The decision tree classification is useful for indicating coastline in the coastal area. The field investigation is performed for recheck the coastline analysis data, land use and land cover in this area.

The coastal change can be distinguished by overlaying the coastline maps of different times. The coastal erosion of the Gulf of Thailand is severe and affected more than 230 kilometers long. In Surat Thani province the main coastal erosion area covers the Don Sak district with the rate of 1.32 meters per year during 2001 to 2009. In Nakhon Si Thammarat province the prominent coastal erosion area is in Ban Laem Talumphuk and Ban Ao Bon with the rate of 4.48 and 8.79 meters per year respectively during 2004 to 2007. In Songkhla province it is occurred in the Ban Map Bua and Ban Tha Bon with the rate of erosion is 1.54 and 1.93 meters per year during 2002 to 2009 respectively. The results of the study reveal only little change for the Andaman Sea coast. In Krabi province the coastal erosion is obvious in the Laem Pho Shell Cemetery of Muang district with the rate of 1.32 meters per year during 1989 to 2001. In Trang province the main coastal erosion area covers the Hat Ratcha Mongkhon and the Hat Pak Meng with the rate of 1.92 and 1.70 meters per year respectively during 1989 to 2001. The coastal erosion of Satun province is evident in the La Ngu districts with the rate of 1.59 meters per year during 2002 to 2007.

5.2 Conclusions

The methods of Normalized Difference Water Index (NDWI) and decision tree classification with the application of remote sensing and GIS have been applied for the coastal change detection analysis. The geomorphologic maps and the coastline maps have been produced in the study. The coastal change which includes coastal erosion, coastal deposition and stable coast, can be detected in the study area by overlying of the coastline maps in difference time. The comparison of the coastal change between the Gulf of Thailand and the Andaman Sea coasts shows that the coastal erosion of the Gulf of Thailand is more severe than the Andaman Sea. As the Gulf of Thailand is mainly covered by clay of an old tidal flat and intertidal flat which is more sensitive to erosion but the Andaman Sea is covered mainly by the more resistant rocky

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APPENDIX A

COASTAL CHANGE IN THE GULF OF THAILAND

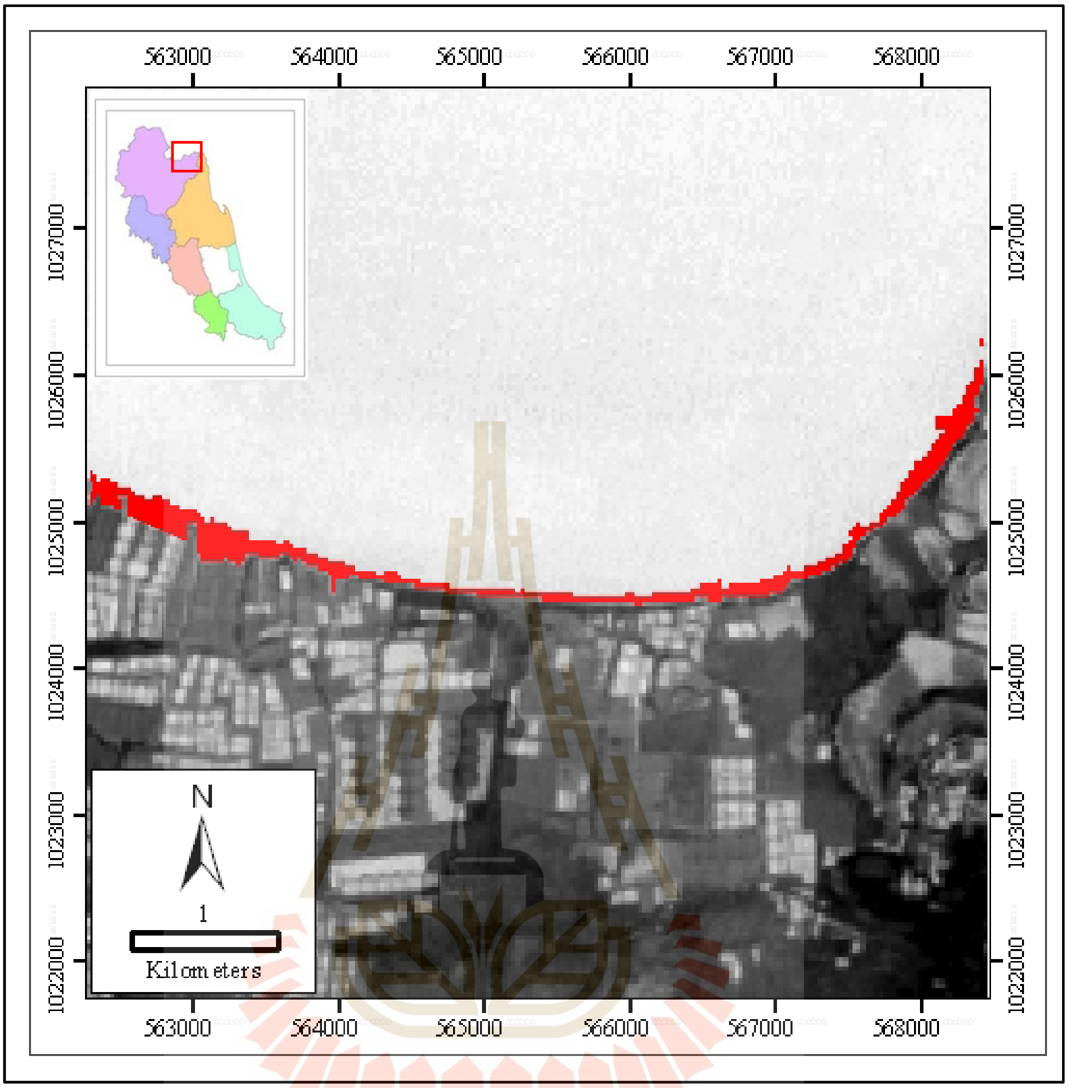

Figure A-1 Map of coastal change between 1994 and 2001 in Ban Phot area (taken on 22/02/2001).

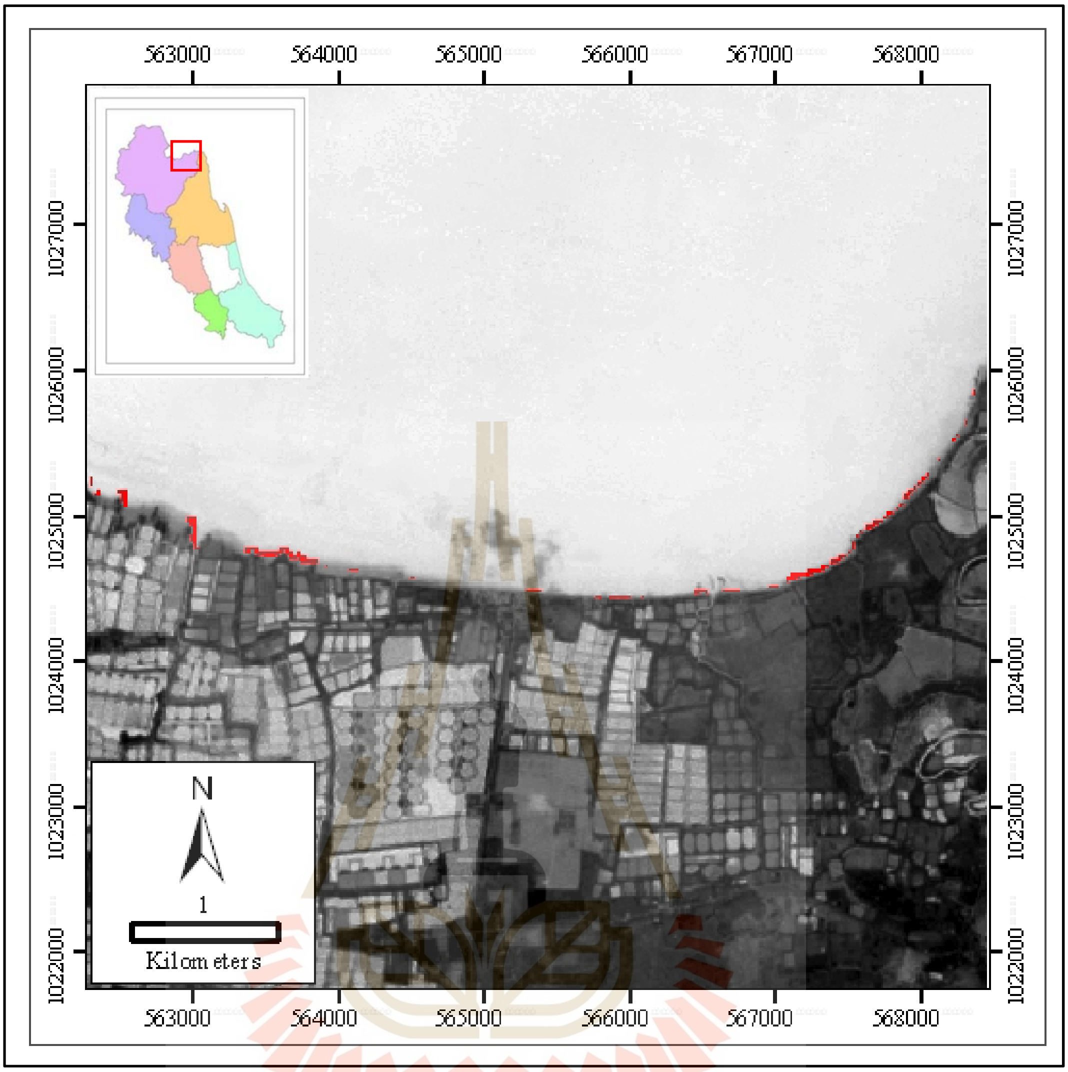

Figure A-2 Map of coastline change between 1994 and 2001 in Ban Phot area (taken on 22/02/2001)

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Figure A-3 Coastal change in Ban Phot (taken on 17/07/2012).

Figure A-4 The seawall in Ban Phot, (taken on 17/07/2012).

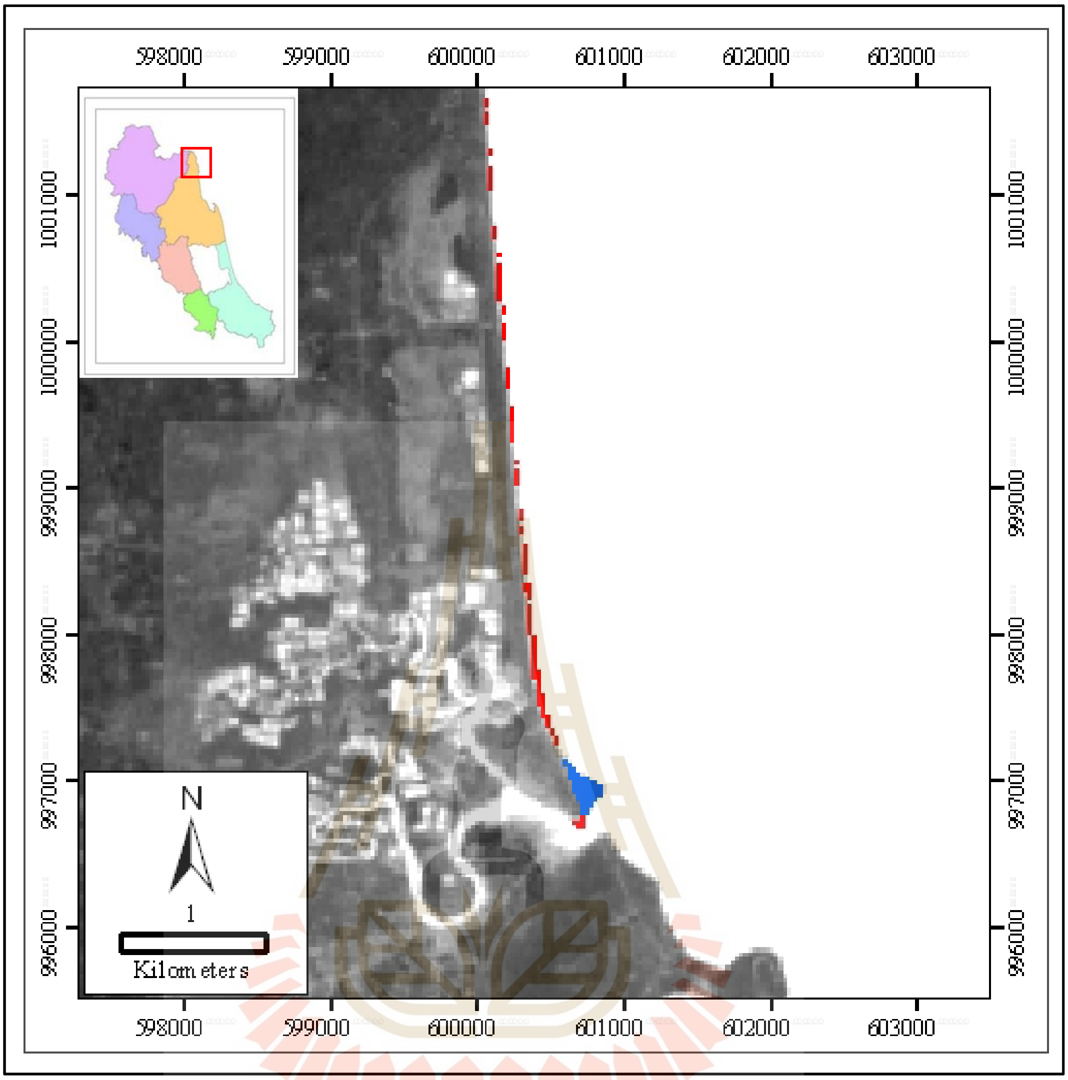

Figure A-5 Map of coastal change between 1994 and 2001 in Ban Fai Tha area (taken on 22/02/2001).

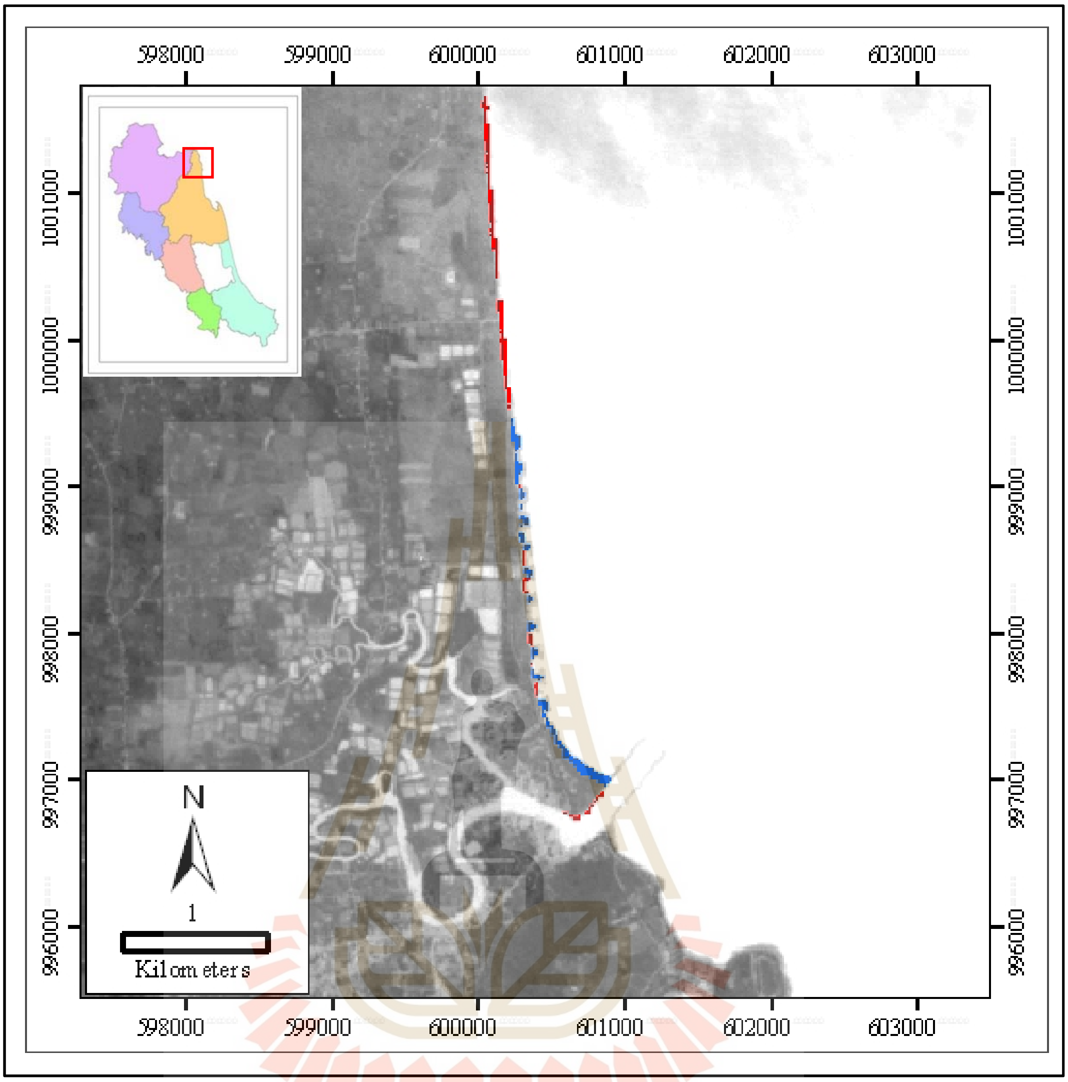

Figure A-6 Map of coastal change between 2001 and 2009 in Ban Fai Tha area (taken on 31/07/2009).

Figure A-7 The breakwaters and jetties in Pak Nam Sichon, (taken on 17/07/2012).

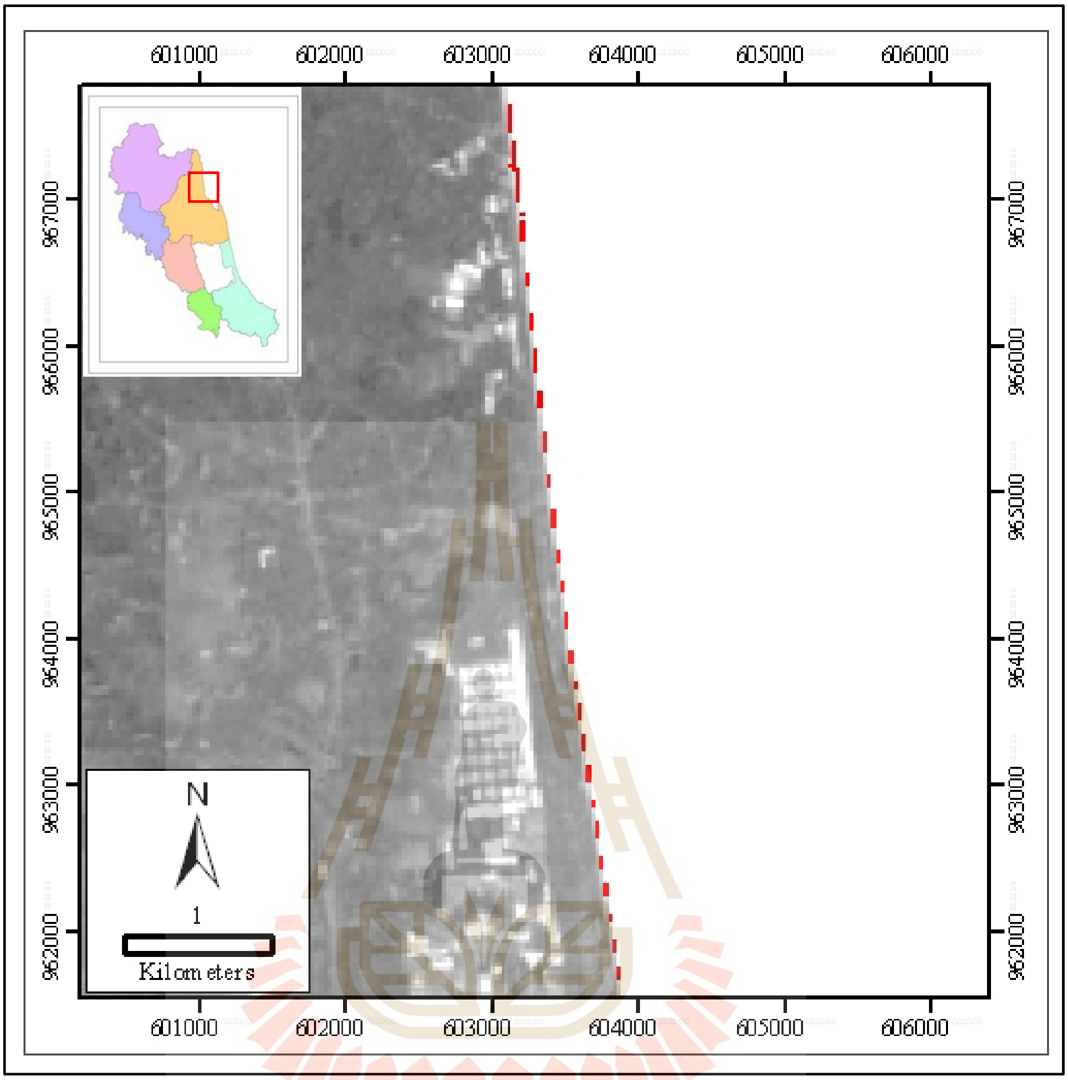

Figure A-8 Map of coastal change between 1994 and 2001 in Ban Ro and Ban Thang Khuen area (taken on 22/02/2001).

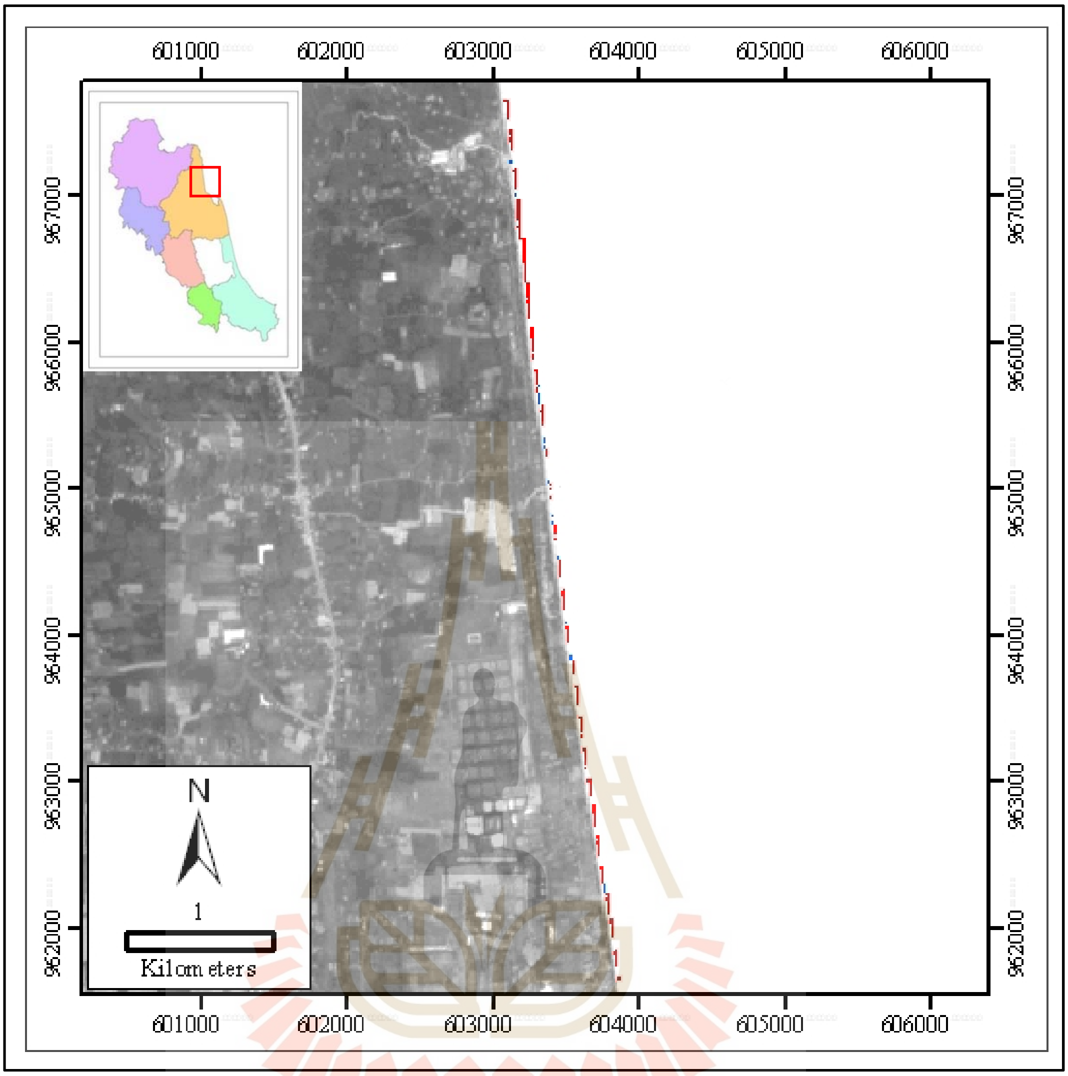

Figure A-9 Map of coastal change between 2001 and 2009 in Ban Ro and Ban Thang Khuen area (taken on 31/07/2009).

Figure A-10 Comparative of coastal change into two periods between 29 January, 2011 (top) and 17 July, 2012 (bottom), in Ban Ro area.

Figure A-11 Comparative of coastal change into two periods between 29 January, 2011 (top) and 17 July, 2012 (bottom), in Wat Thang Khuen.

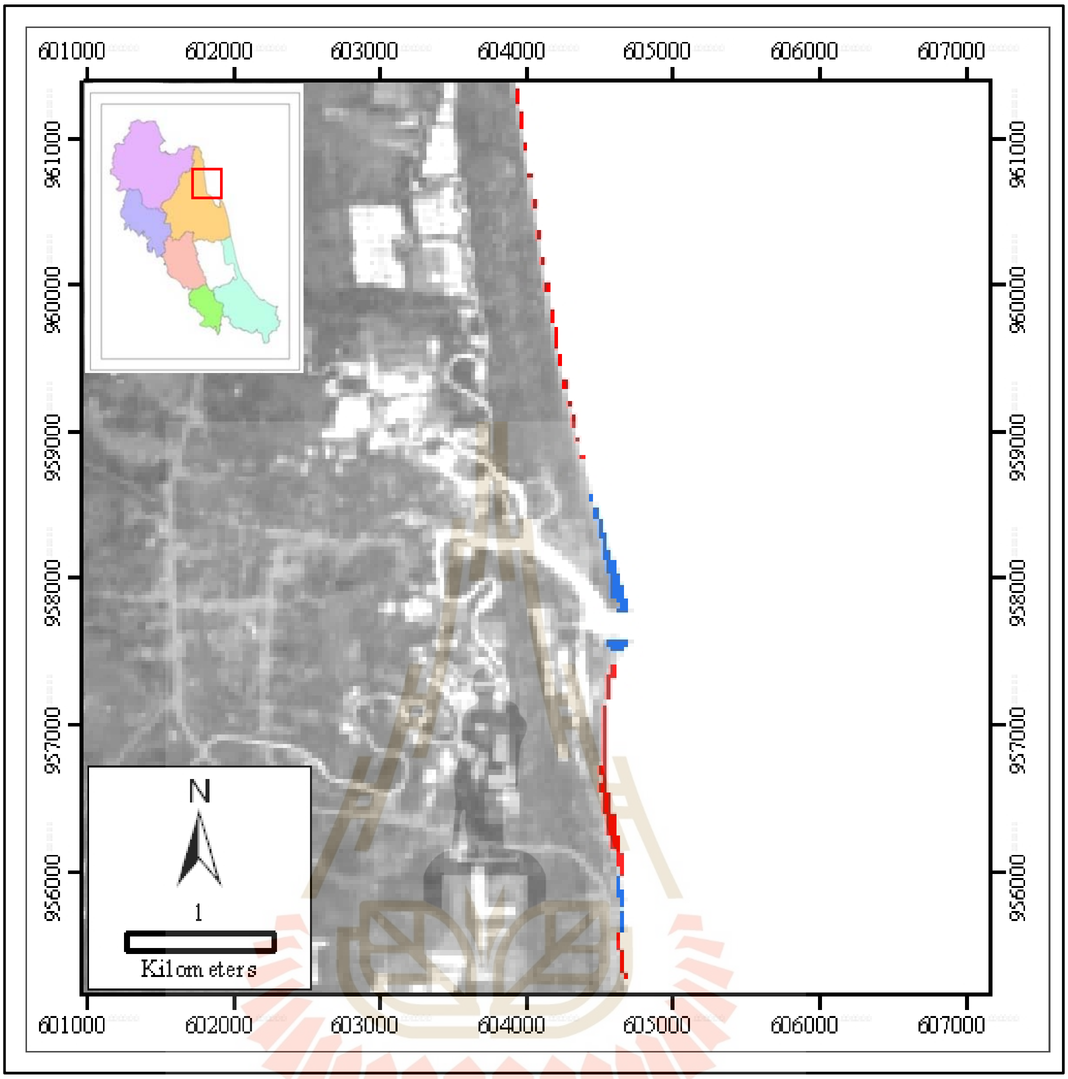

Figure A-12 Map of coastal change between 1994 and 2001 Ban Tha Sung Bon area (taken on 22/02/2001).

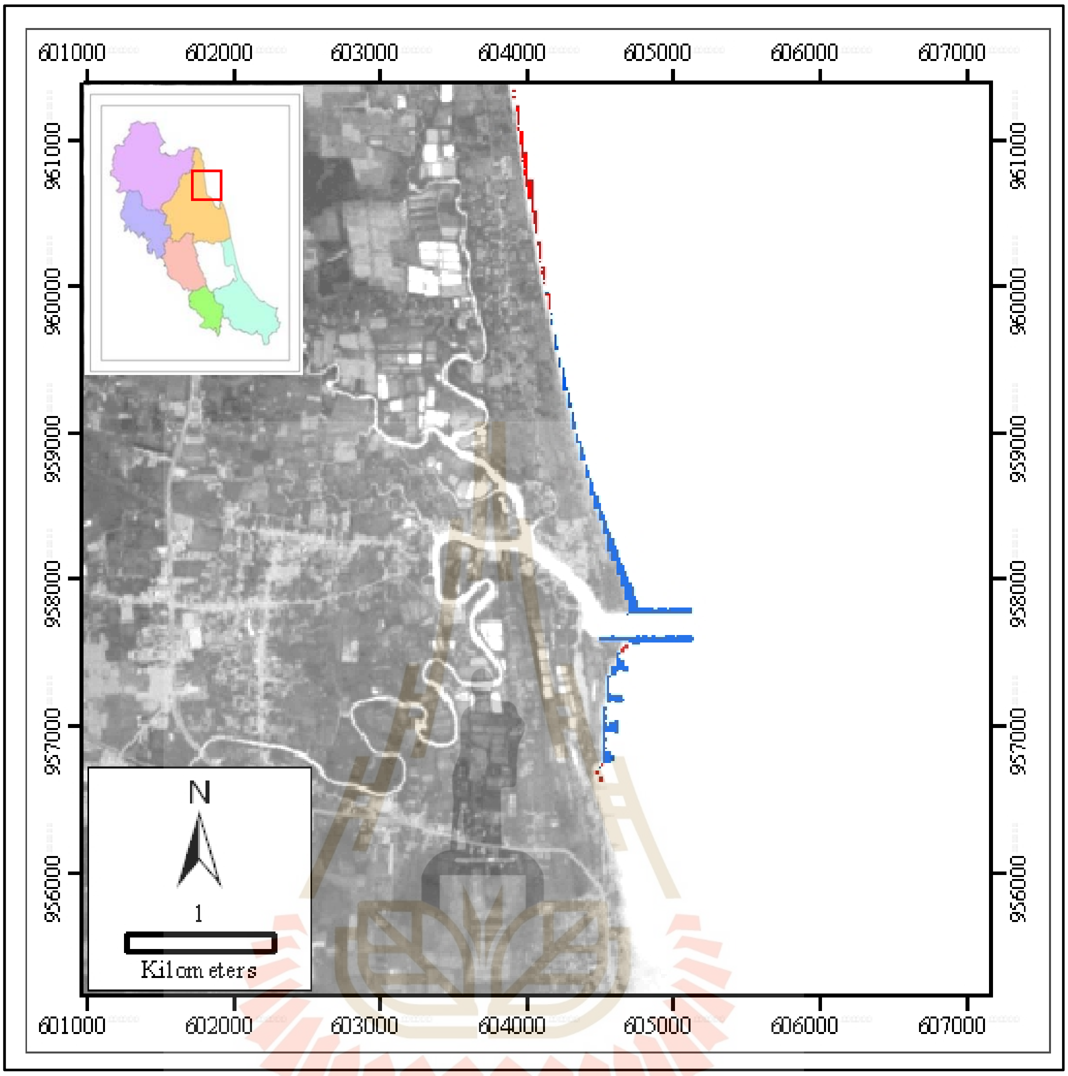

Figure A-13 Map of coastal change between 2001 and 2009 in Ban Tha Sung Bon area (taken on 31/07/2009).

Figure A-14 The jetties, breakwaters, and groins in Ban Tha Sung Bon and Hat Dan Phasi,(taken on 18/07/2012).

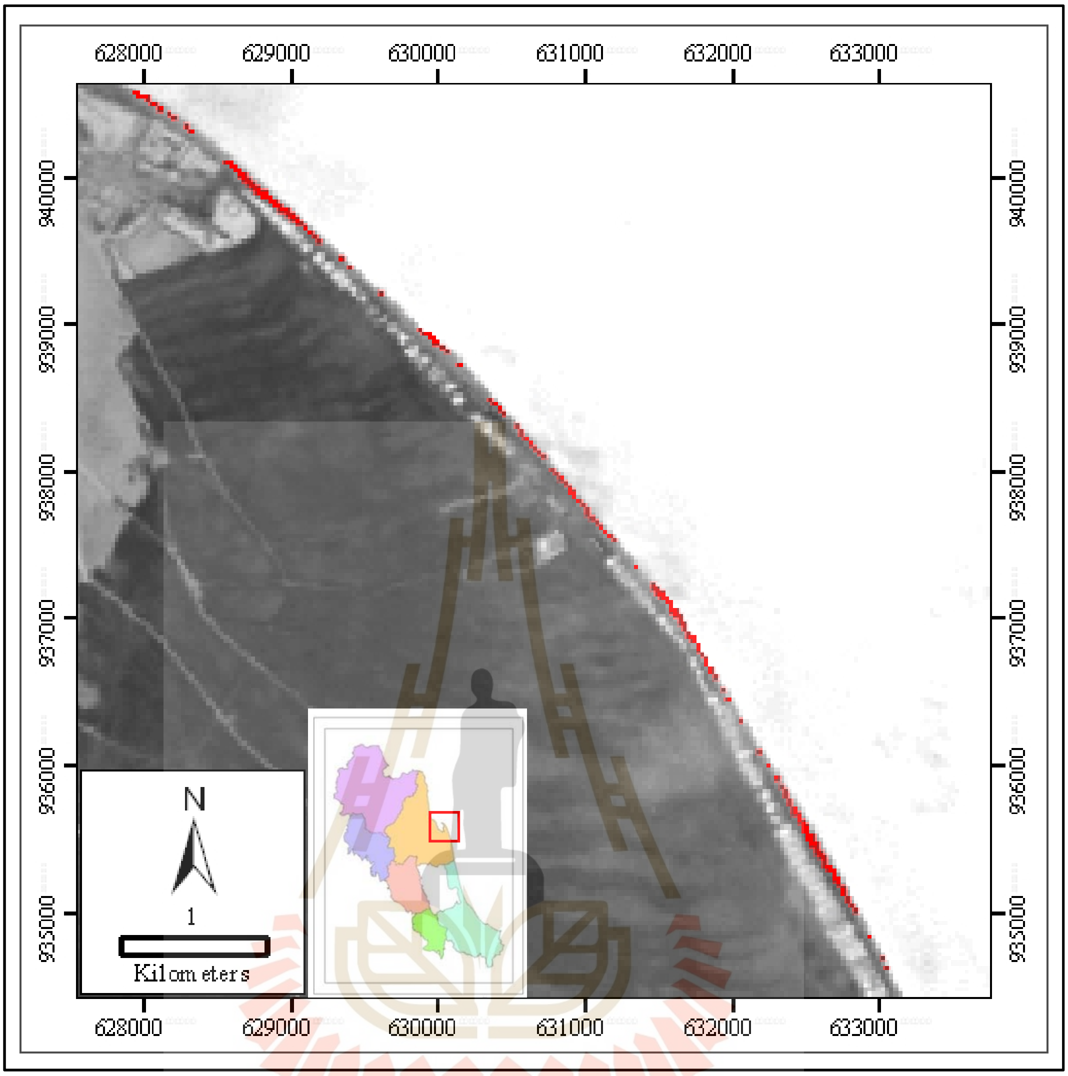

Figure A-15 Map of coastal change between 1994 and 2004 in Ban LaemTalumphuk area (taken on 10/08/2004).

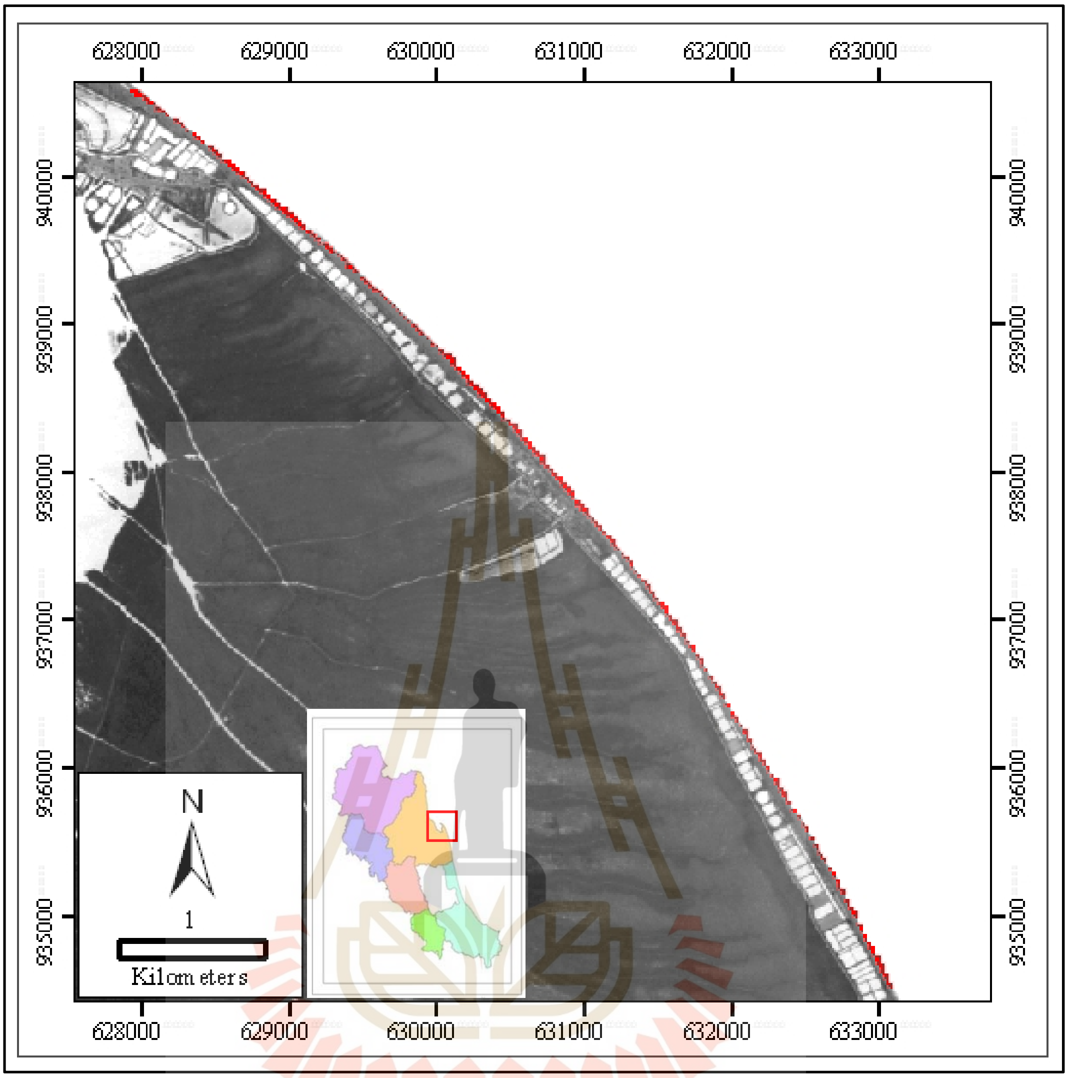

Figure A-16 Map of coastal change between 2004 and 2007 in Ban Laem Talumphuk area (taken on 16/03/2007).

Figure A-17 Coastal change in Ban Laem Talumphuk (taken on 30/01/2011).

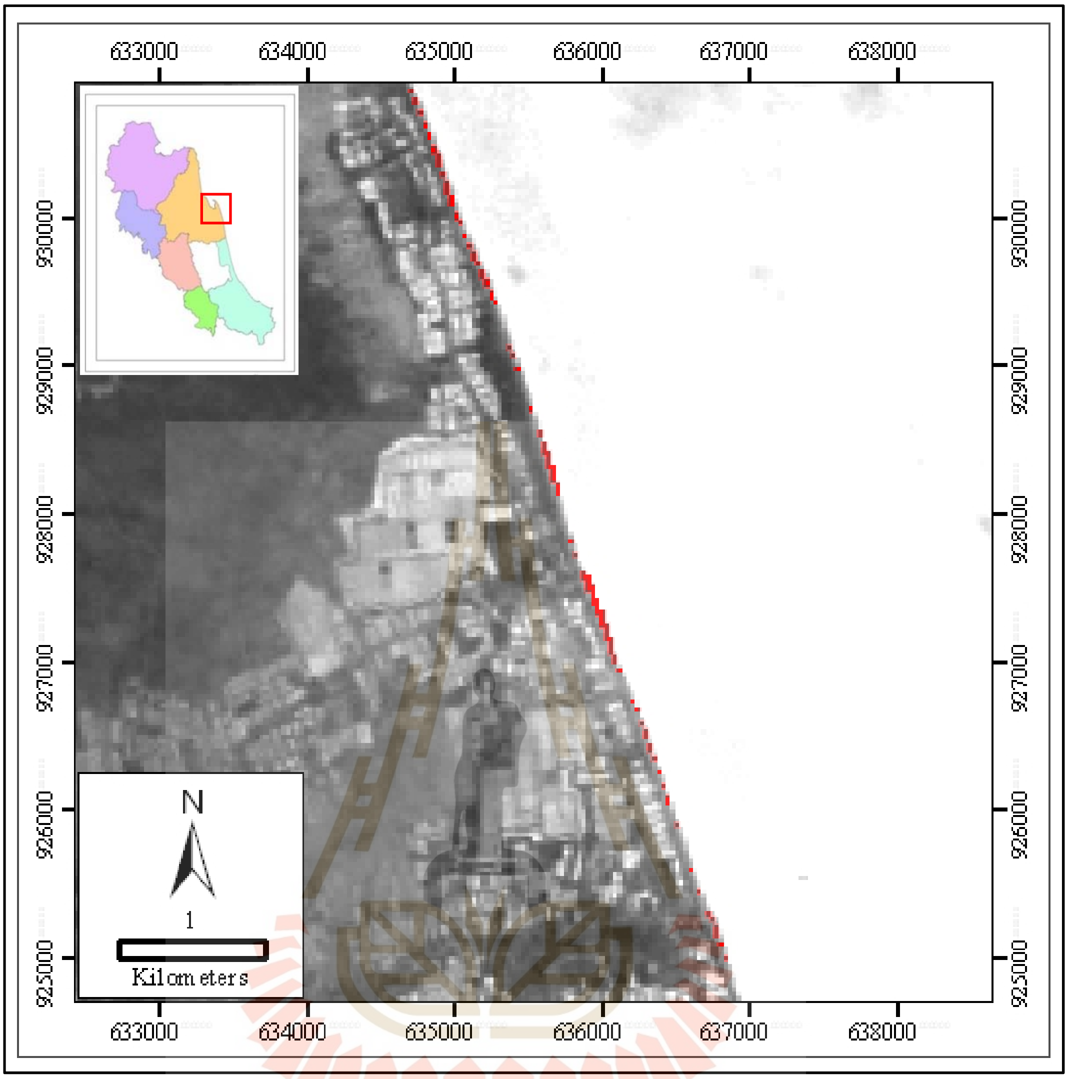

Figure A-18 Map of coastal change between 1994 and 2004 in Ban Chai Thale area (taken on 10/08/2004).

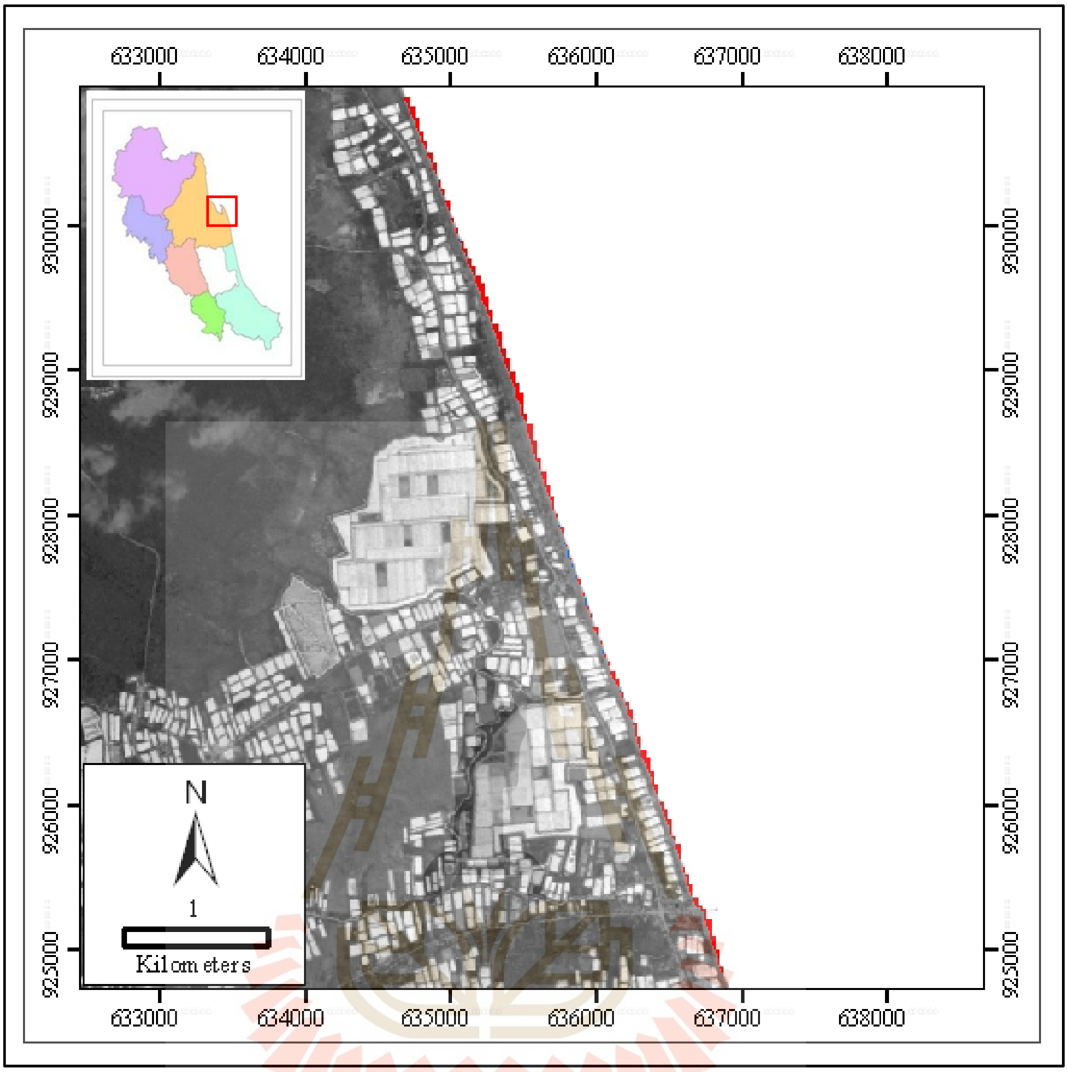

Figure A-19 Map of coastal change between 2004 and 2007 in Ban Chai Thale area (taken on 16/03/2007).

Figure A-20 Coastal change in Ban Hua Thanon Chai Thale (taken on 30/01/2011).

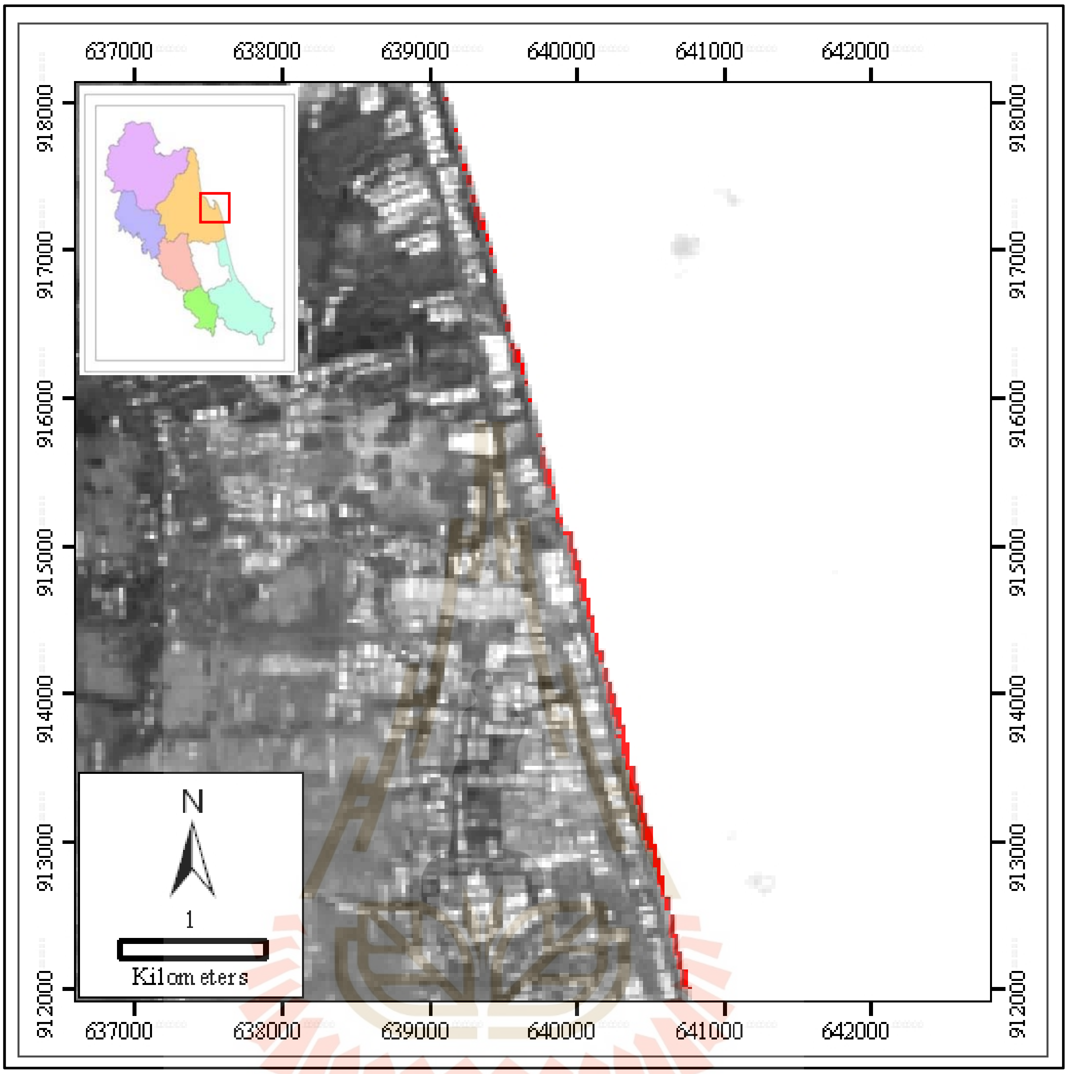

Figure A-21 Map of coastal change between 1994 and 2004 in Ban Ao Bon area (taken on 10/08/2004).

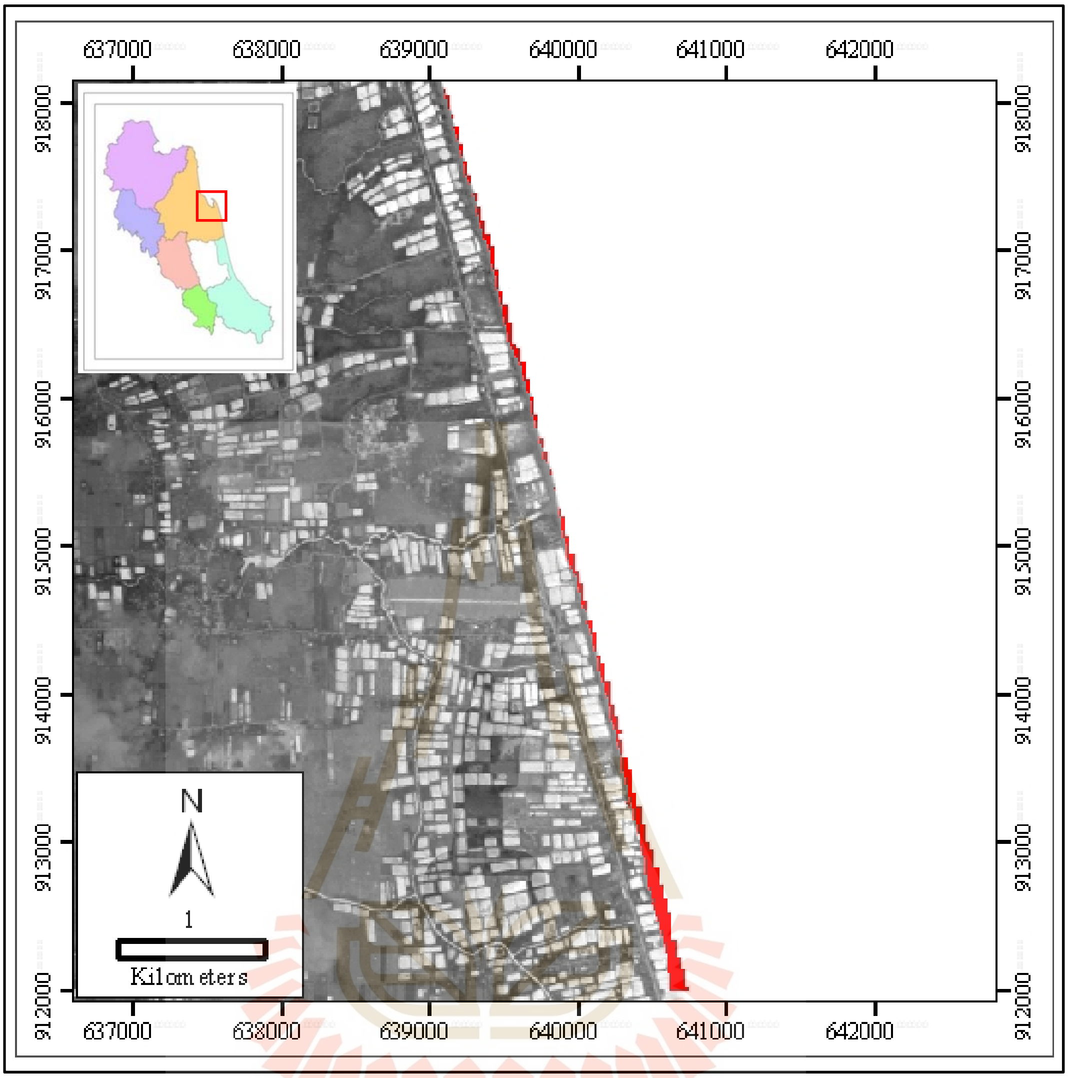

Figure A-22 Map of coastal change between 2004 and 2007 in Ban Ao Bon area (taken on 16/03/2007).

Figure A-23 The severe coastal erosion in Ban Ko Thang (taken on 19/07/2012).

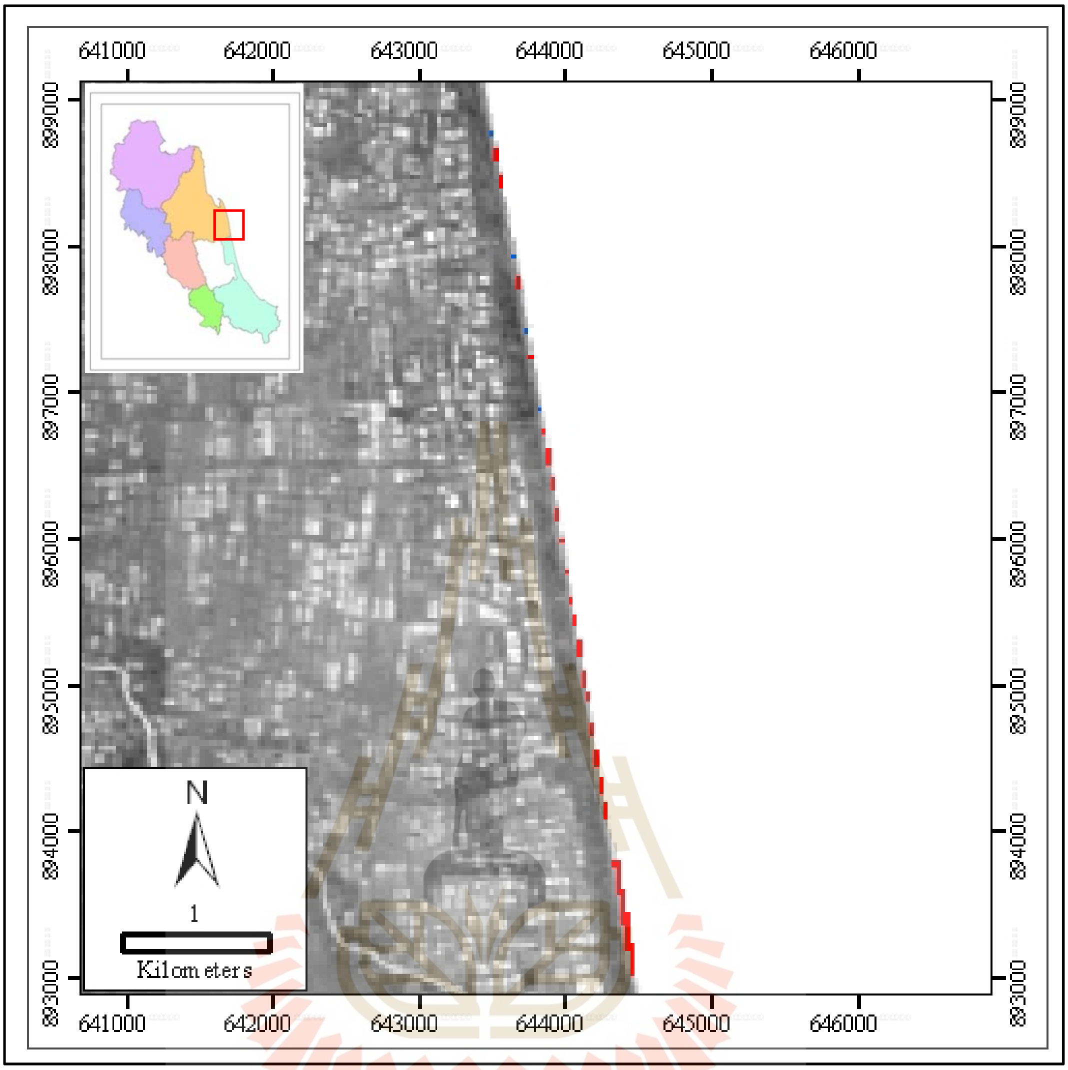

Figure A-24 Map of coastal change between 1994 and 2004 in Ban Na Saton area (taken on 10/08/2004).

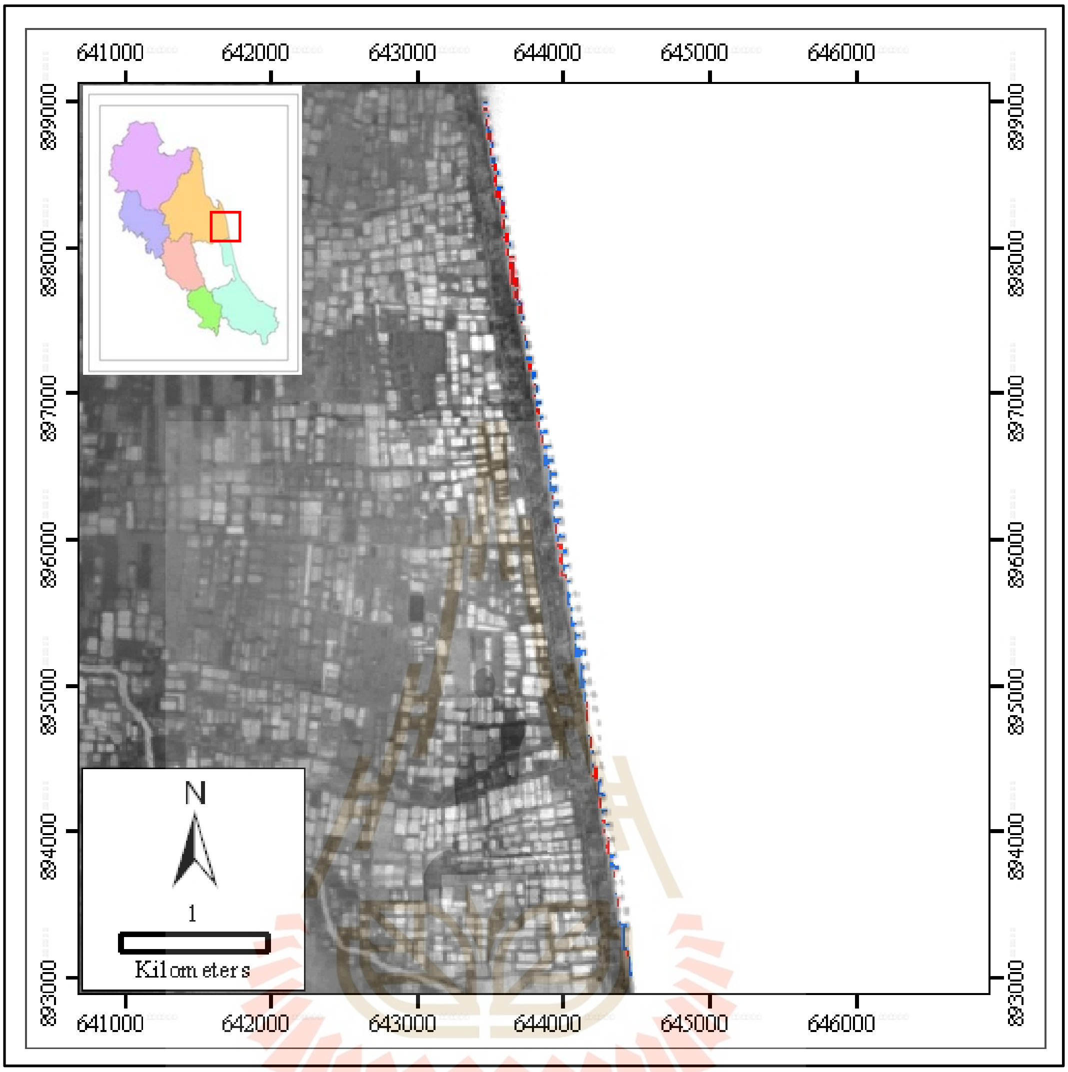

Figure A-25 Map of coastal change between 2004 and 2009 in Ban Na Saton area (taken on 10/07/2009).

Figure A-26 Breakwaters and seawall along road number 4013 (taken on 19/07/2012).

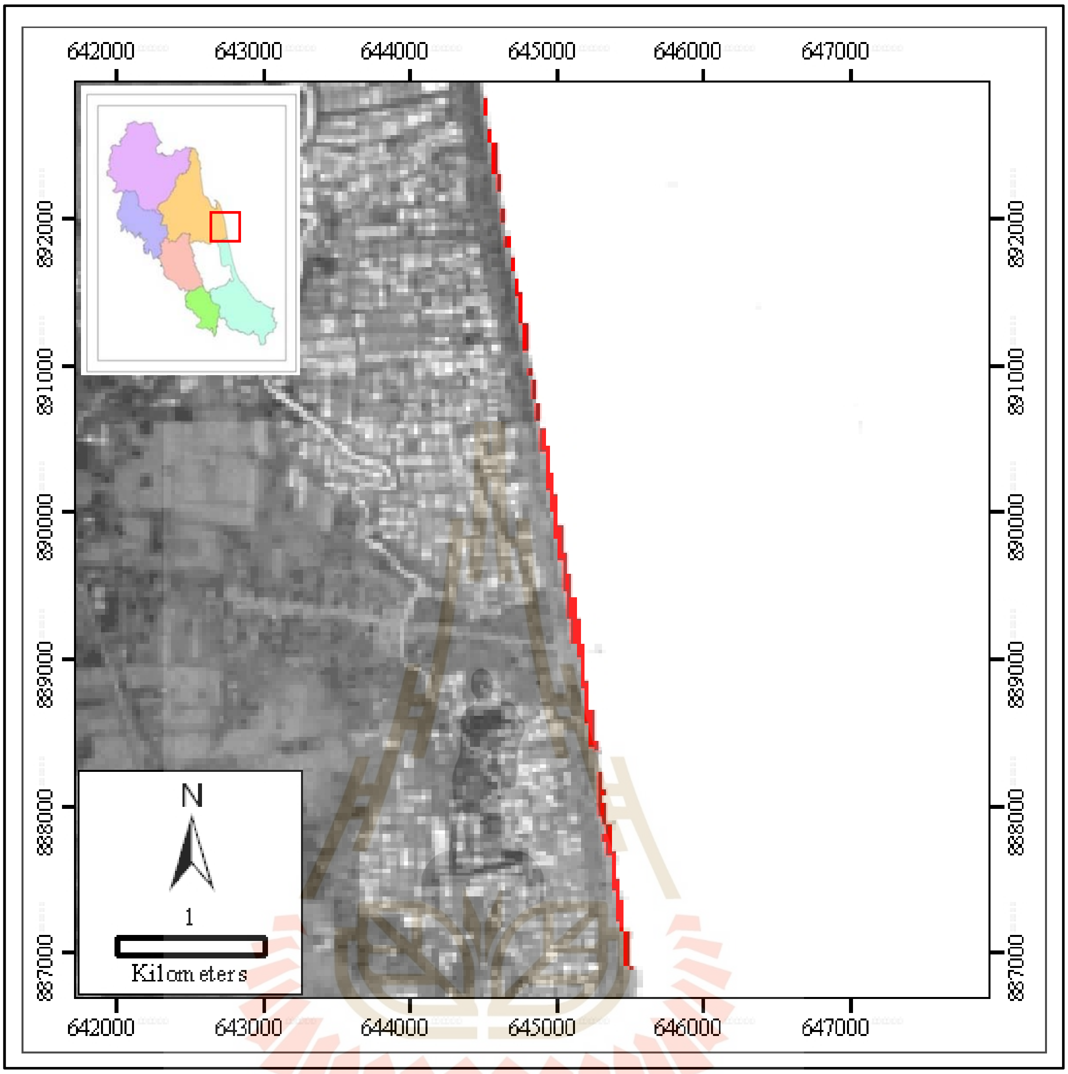

Figure A-27 Map of coastal change between 1994 and 2004 in Ban Na San area (taken on 10/08/2004).

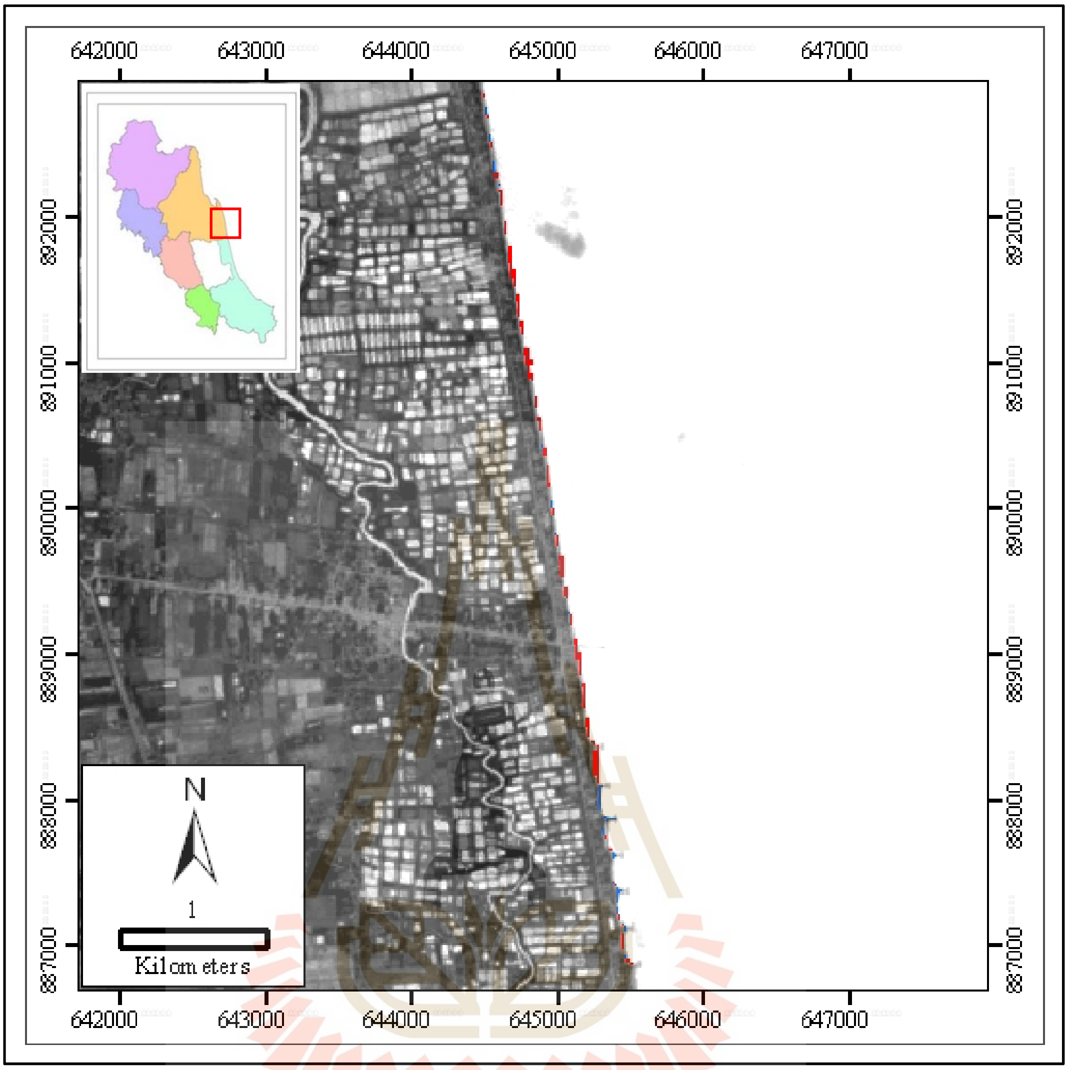

Figure A-28 Map of coastal change between 2004 and 2009 in Ban Na San area (taken on 10/07/2009).

Figure A-29 Breakwater in Ban Na San (taken on 19/07/2012).

Figure A-30 Breakwaters in southern part of Ban Na San (taken on 19/07/2012).

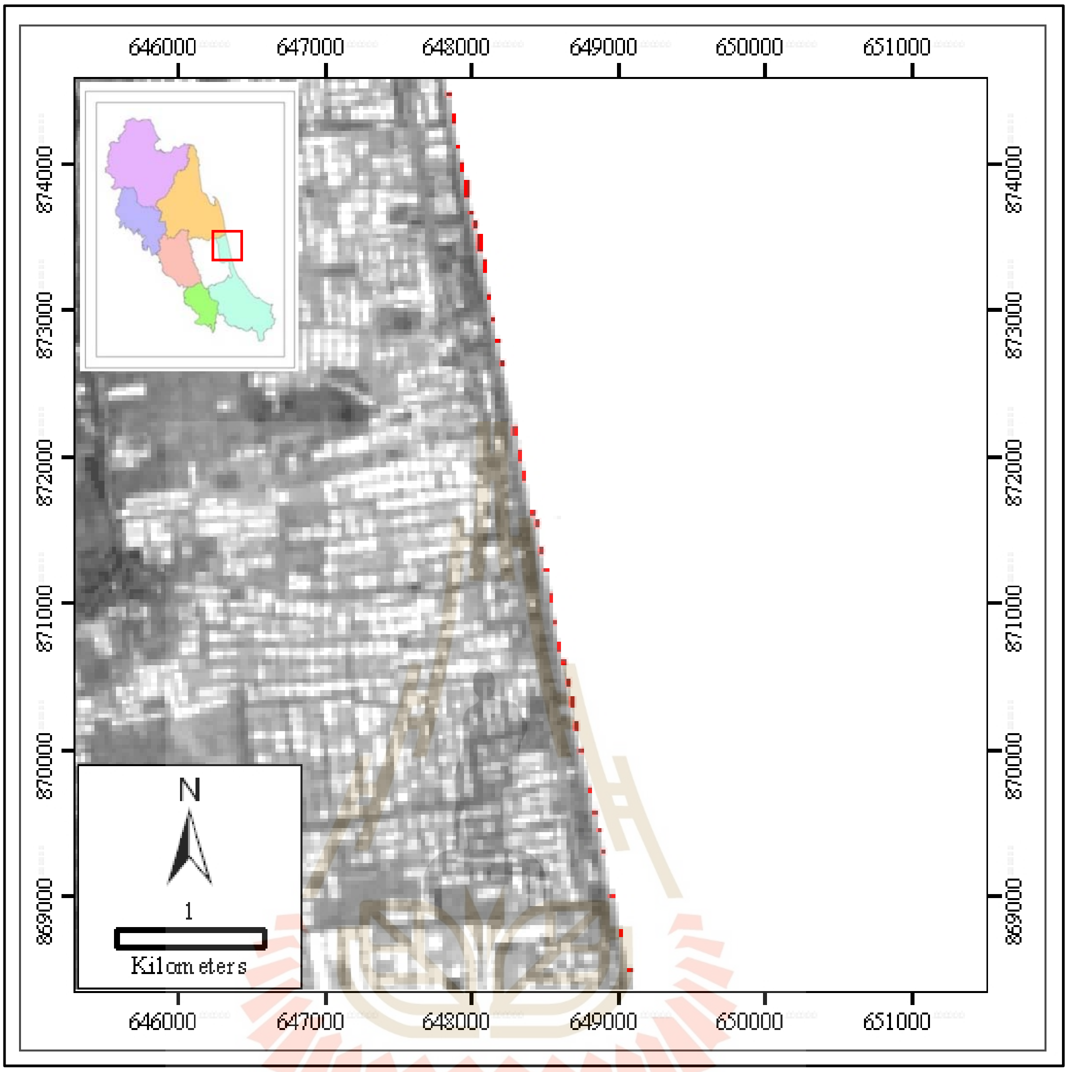

Figure A-31 Map of coastal change between 1990 and 2002 in Ban Map Bua area (taken on 14/09/2002).

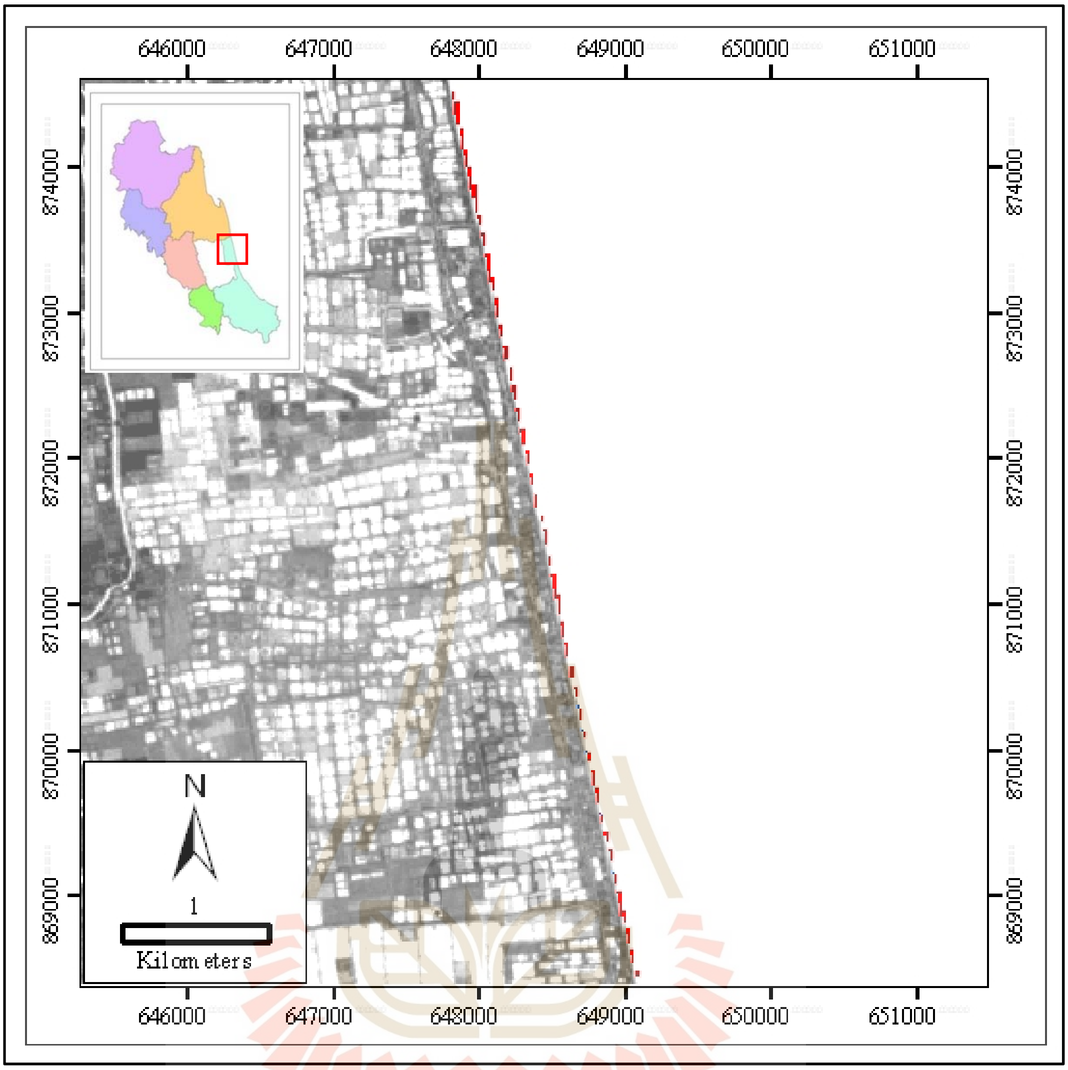

Figure A-32 Map of coastal change between 2002 and 2009 in Ban Map Bua area (taken on 10/07/2009).

Figure A-33 Coastal change in Ban Map Bua (taken on 19/07/2012).

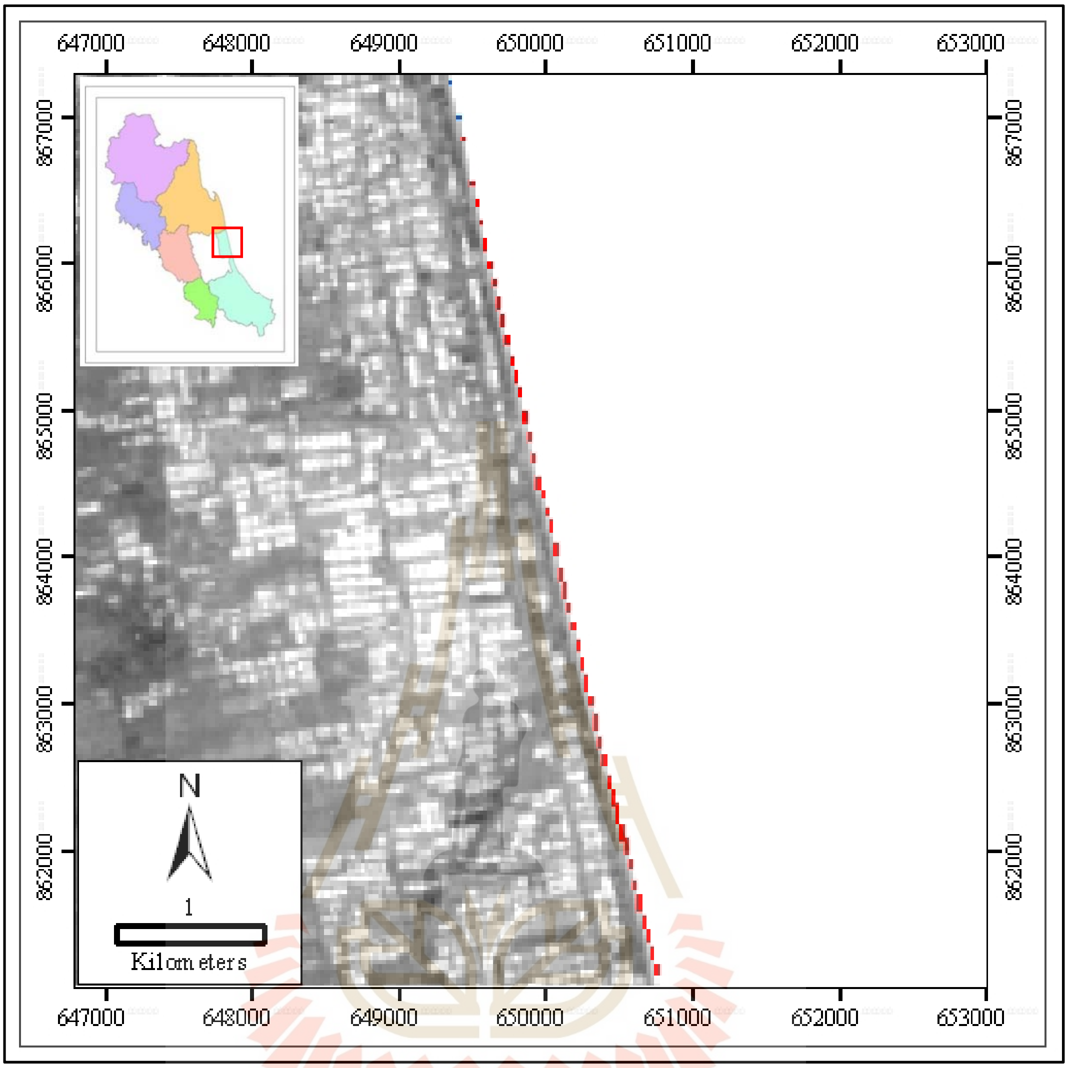

Figure A-34 Map of coastal change between 1990 and 2002 in Ban Tha Bon area (taken on 14/09/2002).

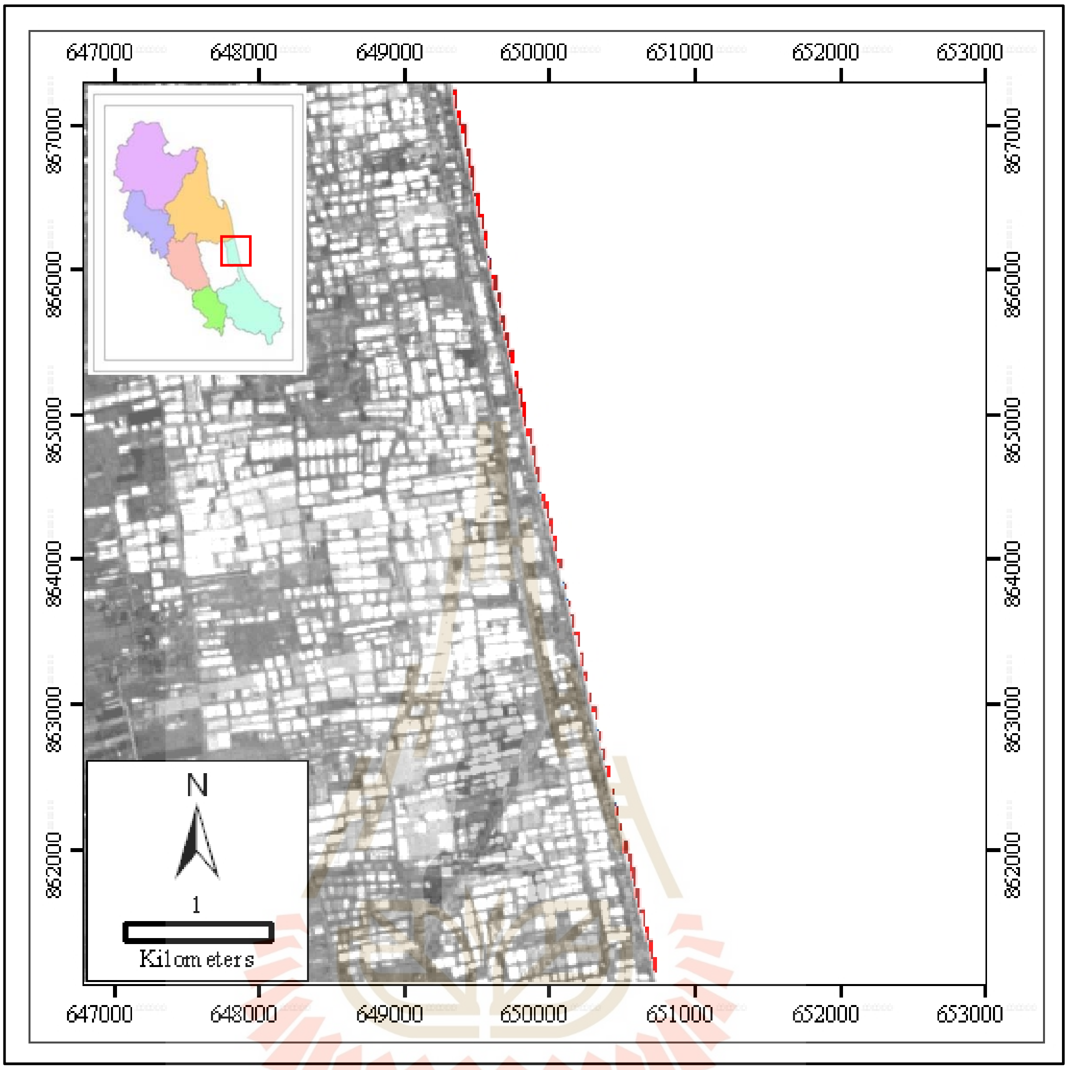

Figure A-35 Map of coastal change between 2002 and 2009 in Ban Tha Bon area (taken on 10/07/2009).

Figure A-36 Coastal change in Ban Tha Bon (taken on 27/03/2011).

APPENDIX B

COASTAL CHANGE IN THE ANDAMAN SEA

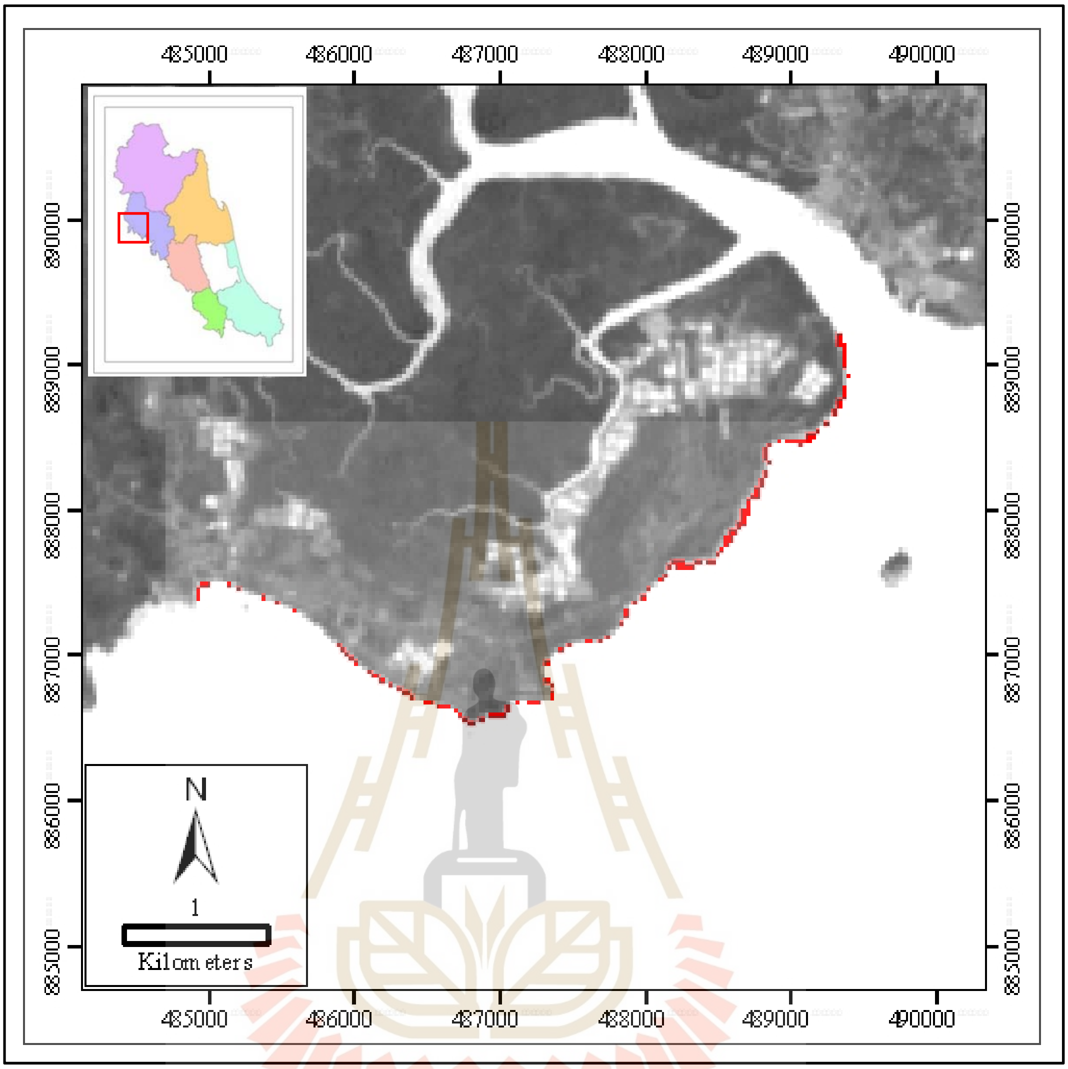

Figure B-1 Map of coastal change between 1989 and 2001 in Ban Laem Pho area (taken on 22/02/2001).

Figure B-2 Coastal change in Laem Pho Shell Cemetery (taken on 21/07/2012).

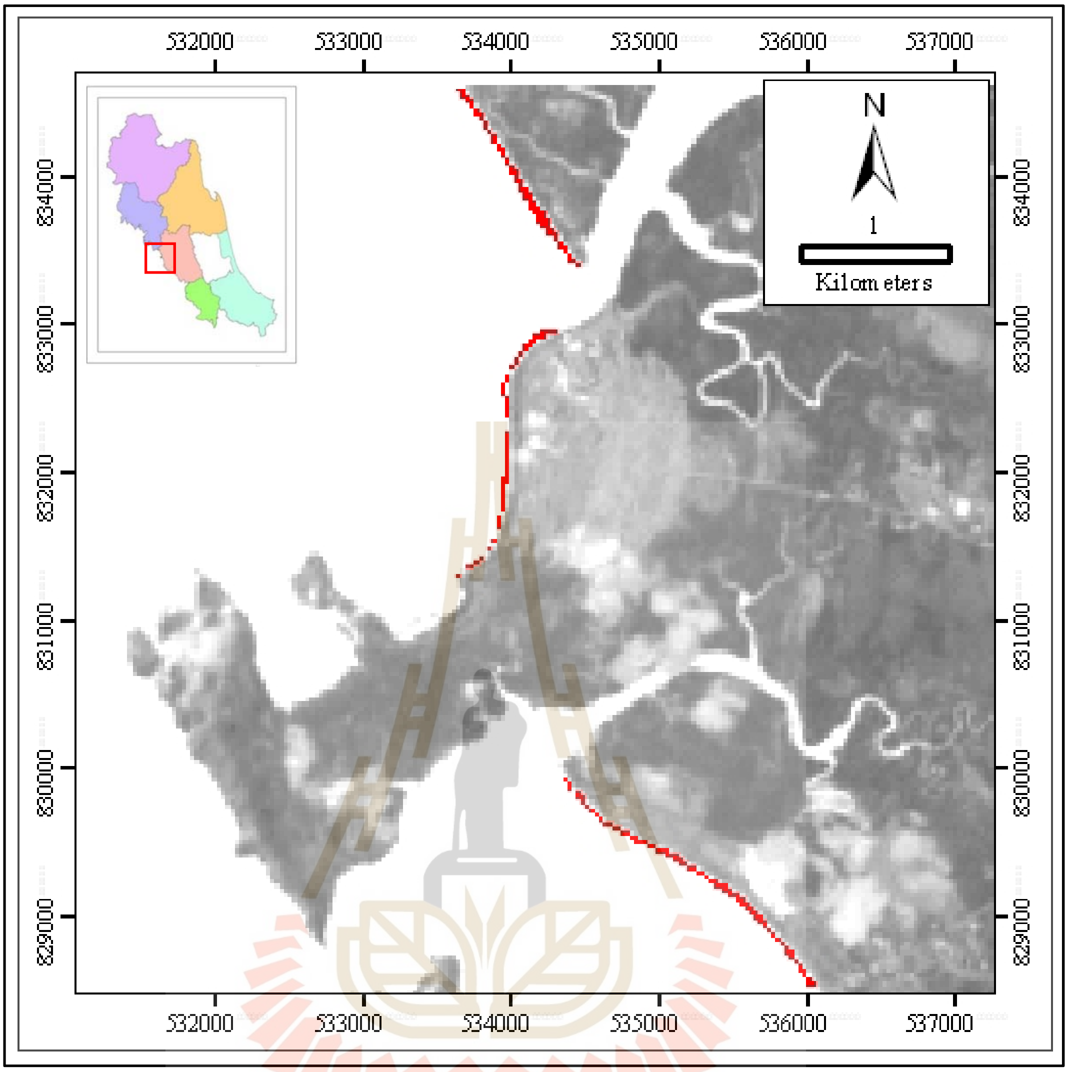

Figure B-3 Map of coastal change between 1989 and 2001 in Hat Ratcha Mongkhon area (taken on 22/02/2001).

Figure B-4 Coastal change in Hat Ratcha Mongkhon (taken on 21/7/2555).

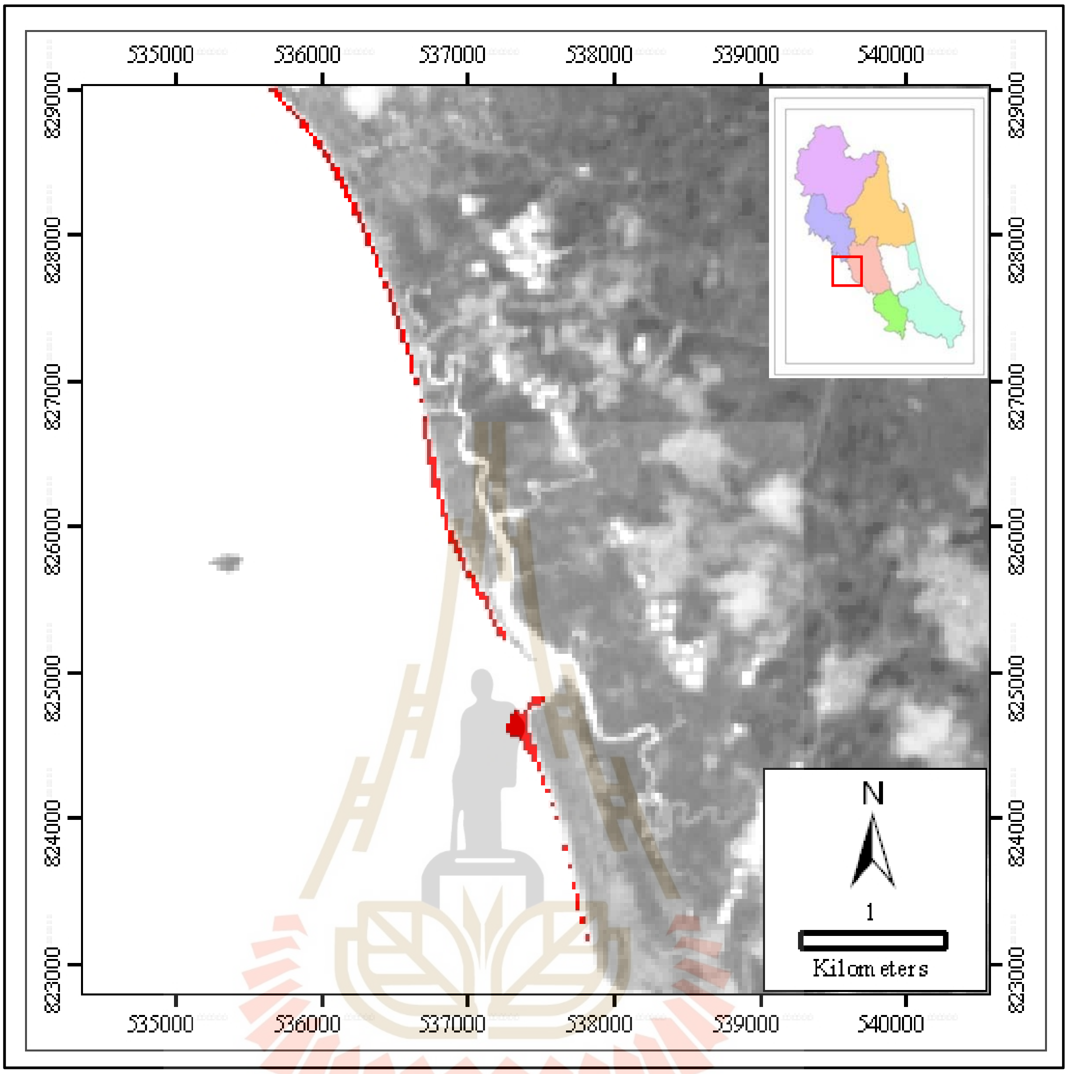

Figure B-5 Map of coastal change between 1989 and 2001 in Ban Pak Meng area (taken on 22/02/2001).

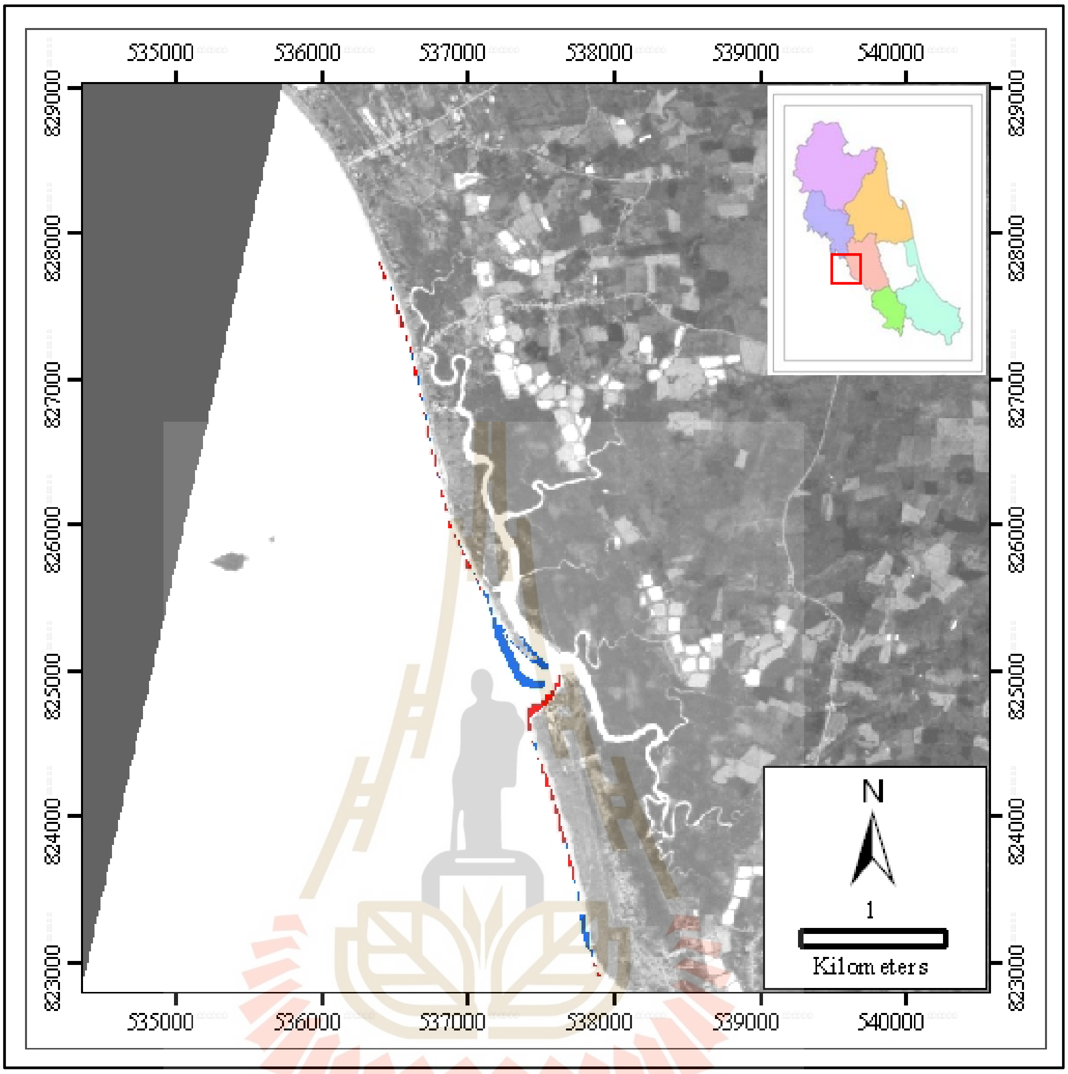

Figure B-6 Map of coastal change between 2001 and 2006 in Ban Pak Meng area (taken on 12/03/2006).

Figure B-7 Small seawall in Hat Pak Meng (taken on 21/7/2555).

Figure B-8 Coastal change in Hat Pak Meng (taken on 21/7/2555).

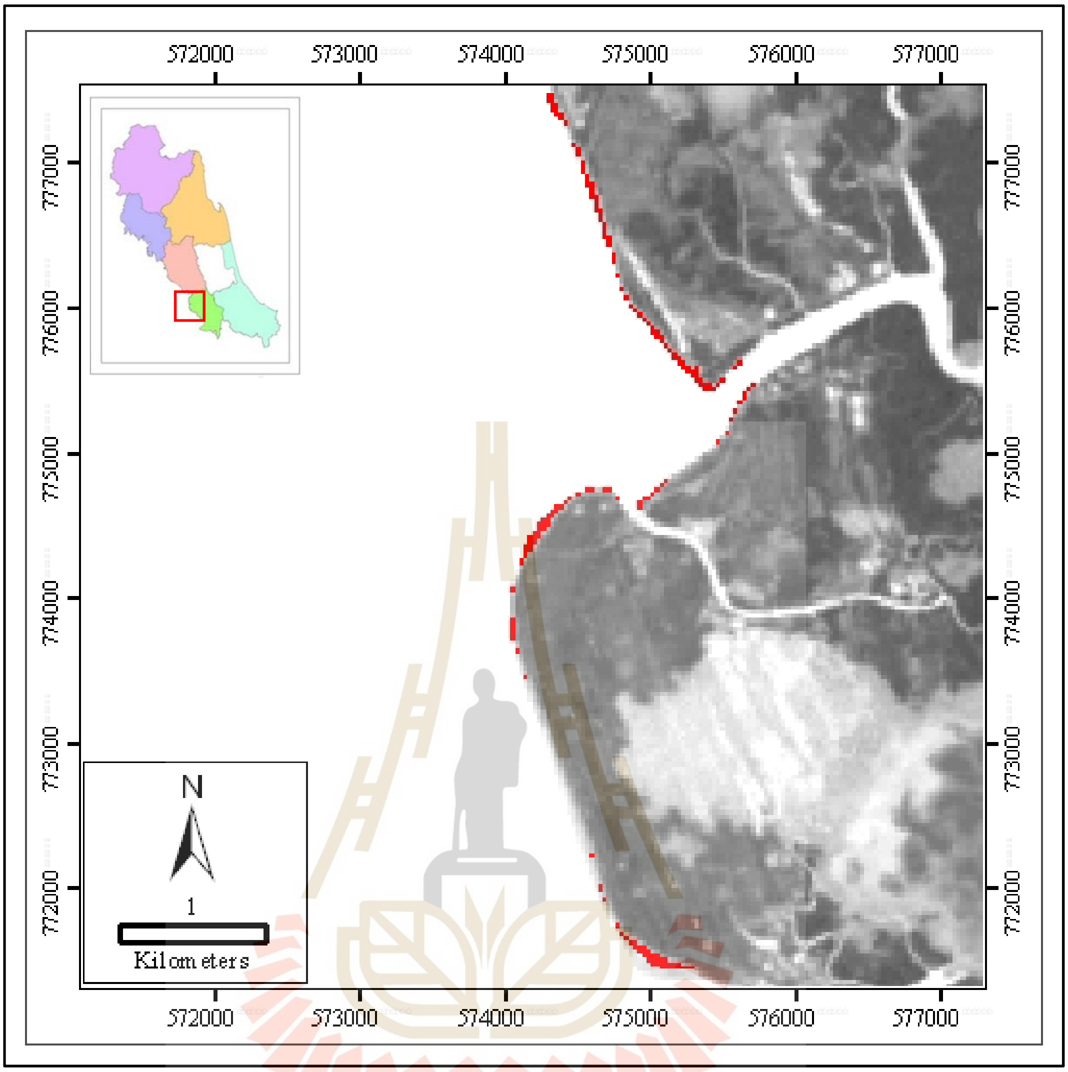

Figure B-9 Map of coastal change between 1989 and 2001 in Ban Ravi and Ban Thung Sabo area (taken on 22/02/2001).

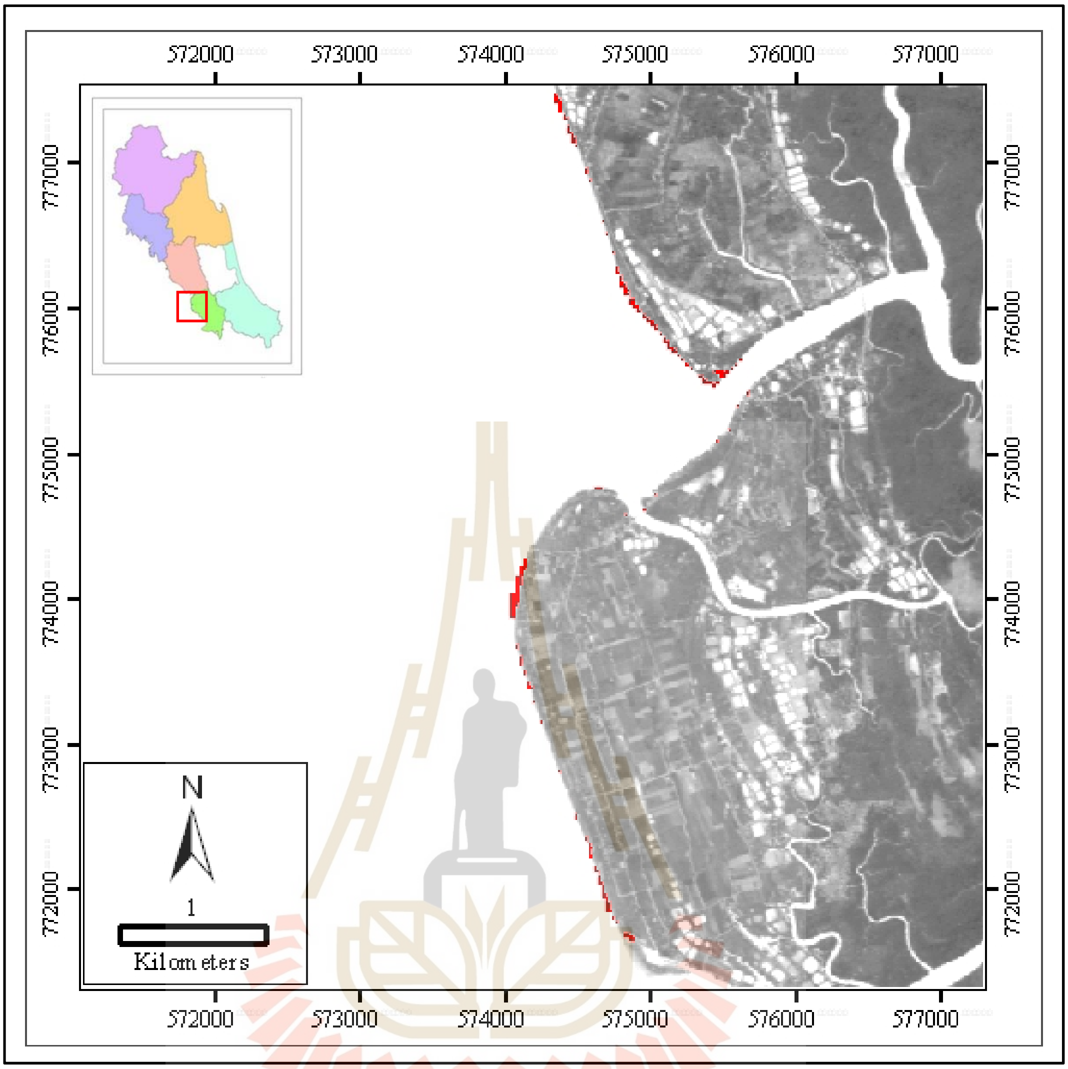

Figure B-10 Map of coastal change between 2001 and 2007 in Ban Ravi and Ban Thung Sabo area (taken on 25/11/2007).

Figure B-11 Seawall in Ban Thung Sabo (taken on 20/07/2012).

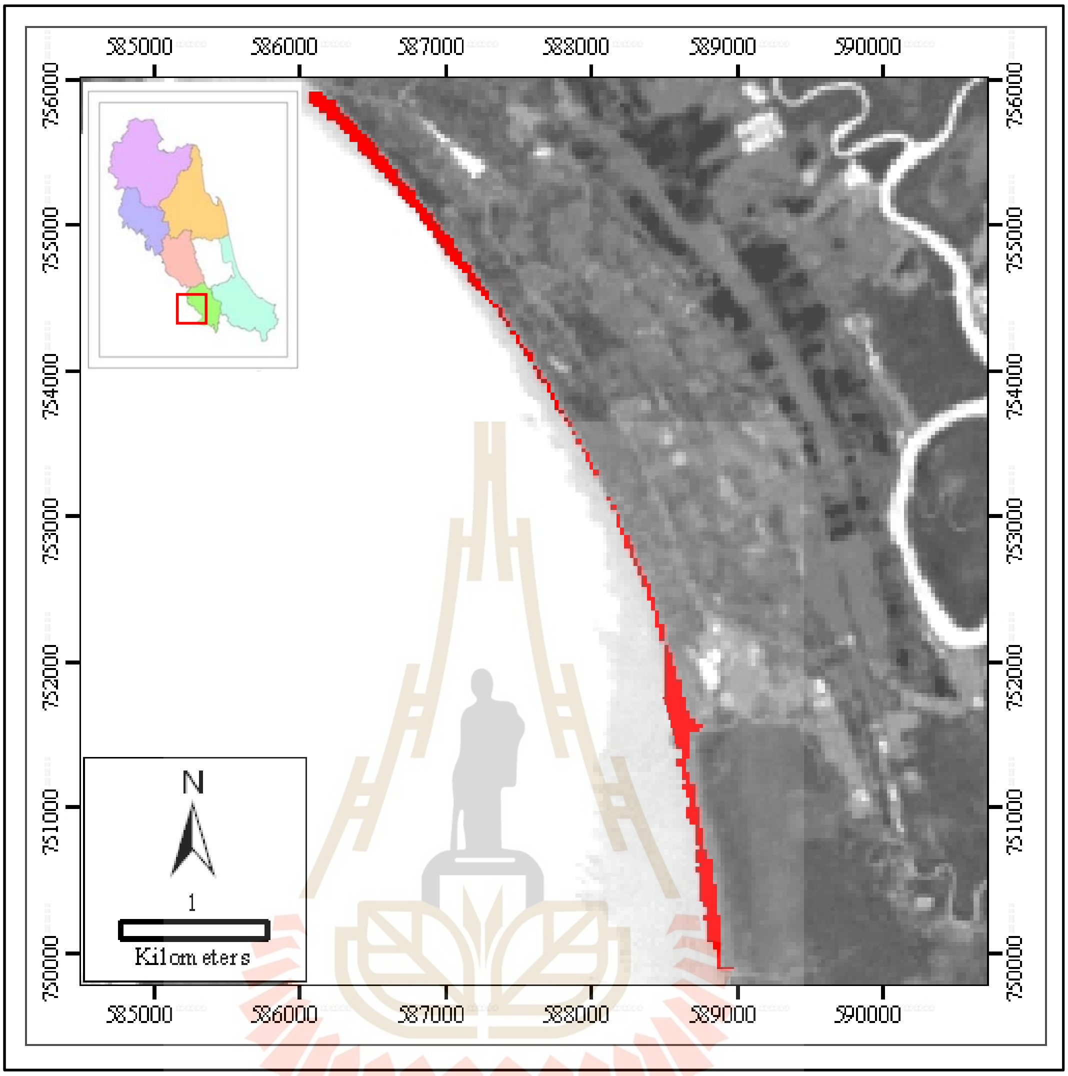

Figure B-12 Map of coastal change between 1990 and 2002 in Ban Pak La Ngu area (taken on 06/03/2002).

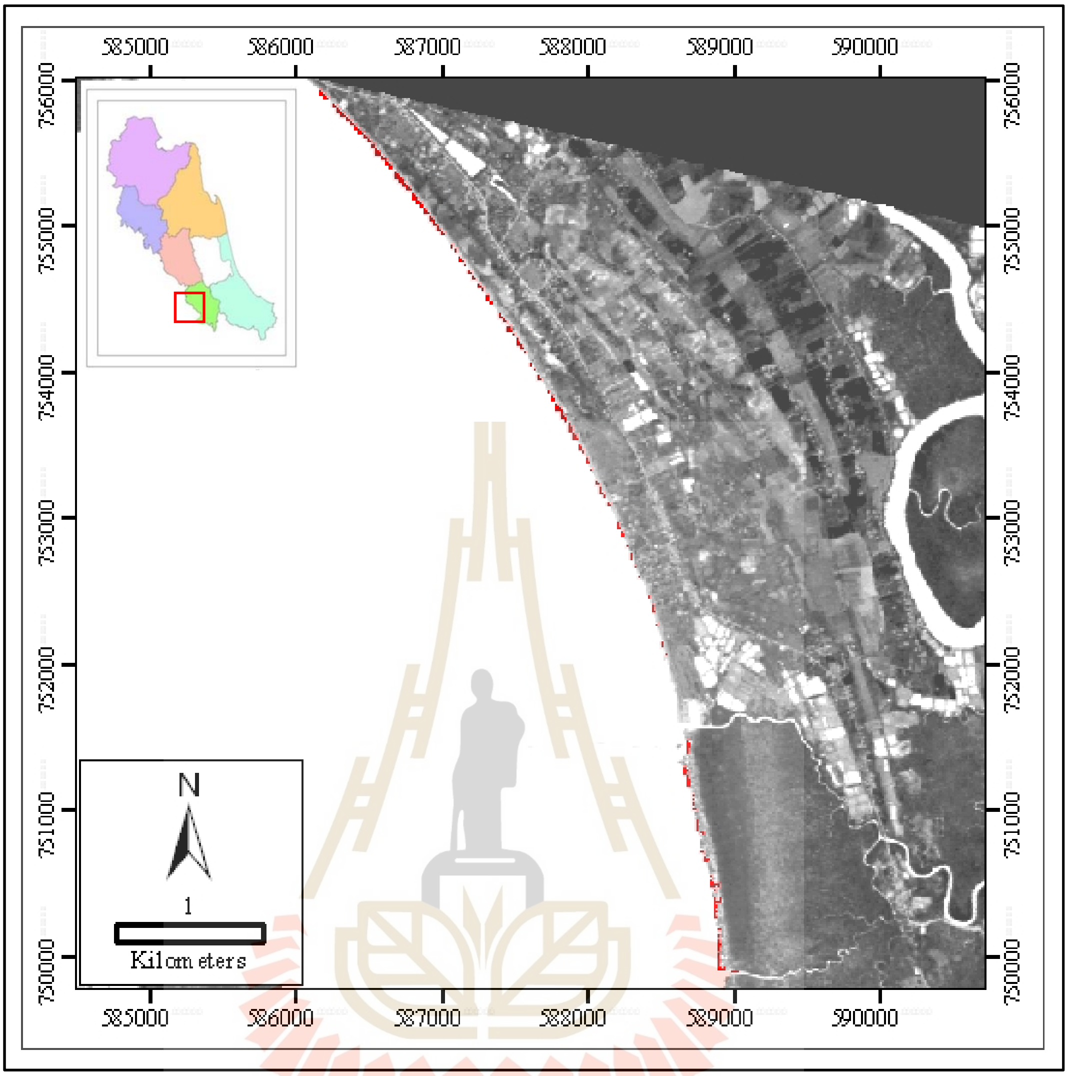

Figure B-13 Map of coastal change between 2002 and 2007 in Ban Pak La Nguu area (taken on 28/02/2007).

Figure B-14 Seawall in Ban Pak La Ngu area (taken on 20/07/2012).

APPENDIX C

TECHNICAL PUBLICATIONS

List of Publications

Wattanaton, N. and Chonglakmani, C. (2012). **Study of Coastal Change Along the Gulf of Thailand Coast Using Remote Sensing Technique and Field Investigation : A Case Study of Nakhon Si Thammarat province**. The 12th Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia. March 2012. Bangkok.

Wattanaton, N. and Chonglakmani, C. (2014). **Comparison of Coastal Change in the Gulf of Thailand and the Andaman Sea : Case Study in Nakhon Si Thammarat and Trang Provinces, Southern Thailand**. International Workshop on Tethyan Orogenesis and Metallogeny in Asia. October 2014. China.

Study of Coastal Change Along the Gulf of Thailand Coast Using Remote Sensing Technique and Field Investigation: A Case Study of Nakhon Si Thammarat Province

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ABSTRACT

Thailand has an extensive coastal area covering 23 provinces of eastern Gulf of Thailand coast of the Pacific Ocean and western Andaman Sea coast of the Indian Ocean. There are about 12 million peoples living in this area. In the gulf of southern Thailand, the coast of Nakhon Si Thammarat province is about 190 kilometers in length and it lies within the Khanom, Sichon, Tha Sala, Muang, Pak Panang and Hua Sai districts. This study uses the Landsat ETM+ satellite imagery scene Path 128 / Row 54 and Path 129 / Row 54 acquired in two periods of 1994 and 2001. The satellite images are processed and analysed by using Band Ratio and Band Math tool of ENVI software. The geomorphologic feature of Quaternary deposits is classified and mapped. It is characterized by subtidal flat, intertidal flat, old tidal flat, young sandy beach, old sandy beach, and old lagoon. The classification of land and water and the mapping of coastline of two periods have been accomplished by using the remote sensing technique. The result of study indicates that several kilometers of the coast of study area especially the Tha Sala and Hua Sai districts have been eroded.

Comparison of coastal change in the Gulf of Thailand and the Andaman Sea: case study in Nakhon Si Thammarat and Trang Provinces, southern Thailand

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Abstract

Thailand has an extensive coastal area covering 23 provinces of the eastern Gulf of Thailand coast of the Pacific Ocean and western Andaman Sea coast of the Indian Ocean. Thailand comprises extensive coastline totaling about 2,637 kilometers in length (DMR, 2002). The Gulf of Thailand coastline extends for 1,700 kilometers and the Andaman Sea coastline for 937 kilometers. These coastal zones are endowed with rich natural resources and are, therefore, important for economic development of the country. In the past, the coastlines have been changed mainly by natural processes, but currently are suffering from human activity including beach pollution, coastal erosion, reduction of coastal wetland, and reduction in sediment supply.

In the gulf of southern Thailand, the coast of Nakhon Si Thammarat Province is about 190 kilometers in length and it lies within the Khanom, Sichon, Tha Sala, Muang, Pak Panang and Hua Sai districts. In the Andaman Sea, the coast of Trang Province is about 150 kilometers in length and it lies within the Sikoa, Kantang, Hat Samran, and Palian districts.

This study uses the Landsat ETM+ satellite imagery scene 128/54, 129/54 and 129/55 acquired in four periods of 1989, 1994, 2001 and 2004. The SPOT imagery scene 263/332, 263/335, 263/336, and 264/333 was acquired in two periods of 2006, 2007. The THEOS imagery scene 263/332, 264/333, and 265/334 werecacquired in two periods of 2007 and 2009. In this study image transformation techniques are used for classification of land and water or coastline by using the ENVI program and GIS techniques.

The satellite images were processed and analysed using the Normalized Difference Water Index (NDWI), decision tree classification and field investigations. The NDWI method reveals the distribution of water and land bodies. The NDWI value is used in decision tree classification and the best value for classification is 0.25. Then the decision tree classification is used for indicating the coastline and field investigations are used to recheck the coastline analysis.

The classification of land and water and the mapping of coastlines in two periods have been accomplished using remote sensing. In Nakhon Si Thammarat Province coastal erosion is severe and has affected a segment more than 60 kilometers long. The prominent coastal erosion area is in Ban

Laem Talumphuk and Ban Ao Bon with a rate of 4.48 meters per year and 8.79 meters per year, respectively during 2004 to 2007. In Trang Province the coastal erosion is severe and has affected about 25 kilometers of beach. The main coastal erosion areas are Hat Ratcha Mongkhon and Hat Pak Meng with rates of 1.92 meters per year and 1.70 meters per year, respectively during 1989 to 2001.

Keywords: *Coastal Change, Remote Sensing, NDWI, Decision Tree Classification*

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BIOGRAPHY

Miss Namporn Wattanaton was born on November 29, 1984 in Samut Songkhram Province, Thailand. She received her Bachelor's Degree in Engineering (Geotechnology), First Class Honors from Suranaree University of Technology in 2006. For her post – graduate, she continued to study with a Ph. D. degree in the Geotechnology Program, Institute of Engineering, Suranaree University of Technology. She received the scholarships from the Commission on Higher Education, Ministry of Education of Thailand and the Royal Golden Jubilee Program of the Thailand Research Fund (RGJ – TRF).