

**IMAGE ENHANCEMENT AND TRANSFORMATION
TECHNIQUES FOR DETECTION OF WETLANDS USING
LANDSAT TM DATA**

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Thesis
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IMAGE ENHANCEMENT AND TRANSFORMATION TECHNIQUES FOR
DETECTION OF WETLANDS USING LANDSAT TM DATA

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ABSTRACT

Wetlands are highly valued for their physical, chemical and biological impact on environmental systems, as well as supporting human economic interests and recreation. However, wetland areas are decreasing continuously due to urbanization and human activities, and there has been a lack of surveying and following up for conservation and prevention. This study aims to find an efficient and appropriate method to survey, detect, and classify wetlands in synthesis.

Remote sensing data from Landsat 5 Thematic Mapper (Landsat 5 TM) in 2007 and spatial data were used with image enhancement and transformation techniques in image processing to detect wetlands in the Phetchaburi basin. Fundamental features of hydrophytic vegetation, hydric soil and hydrology from field surveys in Phetchaburi province were collected and used to lead image processing to classify wetlands for the entire Phetchaburi basin area; supervised classification was used with a maximum likelihood method. All five techniques for image enhancement and transformation were processed.

The study results found that the color composite image technique and the image operation technique with Normalized Difference Vegetation Index (NDVI) are appropriate when used to specify surveying points for field study and in training areas of image data. For the image stretching technique and Principal Component Analysis (PCA) it is appropriate when applied in image classification and detection with a maximum likelihood method. An assessment of accuracy for wetland classification found that the PCA technique has the highest accuracy: 98.92%. Then, a combination of two techniques: image stretching and the PCA technique showed an overall accuracy of 98.78%. For classification that used only linear stretching the overall accuracy was 94.11%, equal to original maximum likelihood using classification without technique.

KEY WORDS: LANDSAT TM/ IMAGE ENHANCEMENT/

IMAGE TRANSFORMATION/ REMOTE SENSING/ WETLANDS

133 pages

การศึกษาเทคนิคในการปรับปรุงคุณภาพและแปลงข้อมูลในการตรวจจับพื้นที่ชุ่มน้ำโดยใช้
ข้อมูล Landsat TM

(IMAGE ENHANCEMENT AND TRANSFORMATION TECHNIQUES FOR DETECTION
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บทคัดย่อ

พื้นที่ชุ่มน้ำได้ให้คุณค่ามหาศาลทั้งทางกายภาพ เคมี และ ชีวภาพในระบบสิ่งแวดล้อม ทั้งยังสนับสนุนค่าจุนระบบเศรษฐกิจ และกิจกรรมสันทนาการของมนุษย์ อย่างไรก็ตามพื้นที่ชุ่มน้ำยังคงลดลงอย่างต่อเนื่องจากกิจกรรมของมนุษย์ และการกลายเป็นเมือง ในขณะที่การสำรวจติดตามเฟื้อระวัง และการป้องกันพื้นที่ชุ่มน้ำสู่การอนุรักษ์ยังคงมีอยู่อย่างจำกัด การศึกษาจึงมุ่งเน้นการศึกษาซึ่งนำมาสู่วิธีการที่เหมาะสมในการสำรวจ และตรวจจับ หรือสังเคราะห์จำแนกพื้นที่ชุ่มน้ำได้อย่างมีประสิทธิภาพ ข้อมูลจากการสำรวจระยะไกลของดาวเทียม Landsat 5 TM ปี 2550 และข้อมูลทางพื้นที่ถูกนำมาใช้ร่วมกับเทคนิคการปรับปรุงและการแปลงคุณภาพข้อมูล ในการจัดการข้อมูลดาวเทียมของพื้นที่ชุ่มน้ำลุ่มน้ำเพชรบุรี ลักษณะพื้นฐานบางประการของพืชพรรณ ดิน และน้ำจากภาคสนามในจังหวัดเพชรบุรีถูกใช้ในการจัดการข้อมูล เพื่อการจำแนกพื้นที่ชุ่มน้ำของพื้นที่ทั้งลุ่มน้ำ โดยการจำแนกแบบก้ำกับลูแล ด้วยวิธีแบบความเป็นไปได้สูงสุดร่วมกับเทคนิคการปรับปรุงและการแปลงคุณภาพข้อมูลทั้ง 5 วิธี การศึกษาพบว่าเทคนิคการสร้างภาพสีผสมเท็จ และการปฏิบัติการระหว่างภาพแบบดัชนีพืช สนับสนุนการกำหนดจุดสำรวจภาคสนามและพื้นที่ตัวอย่างในภาพข้อมูลดาวเทียม เพื่อสนับสนุนการจัดการข้อมูลภาพเบื้องต้น ส่วนเทคนิคการขยายระดับค่าการสะท้อน และการวิเคราะห์องค์ประกอบหลักสามารถใช้ในขั้นของการจำแนกข้อมูลภาพแบบก้ำกับลูแลด้วยวิธีความเป็นไปได้สูงสุด โดยการจำแนกที่ใช้เทคนิคการวิเคราะห์องค์ประกอบหลักให้ค่าความถูกต้องในการจำแนกโดยรวมสูงสุด ร้อยละ 98.92 รองมา คือการจำแนกที่ใช้ร่วมกับ 2 เทคนิค คือ การขยายระดับค่าการสะท้อนเชิงเส้น และการวิเคราะห์องค์ประกอบหลัก ให้ร้อยละค่าความถูกต้องโดยรวมร้อยละ 98.78 ส่วนการจำแนกที่ใช้ร่วมกับเทคนิคการขยายระดับค่าการสะท้อนเชิงเส้น ให้ค่าความถูกต้องโดยรวมร้อยละ 94.11 ซึ่งเท่ากับการจำแนกต้นฉบับที่ไม่ใช้เทคนิค

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CHAPTER I

INTRODUCTION

1.1 Background and Rationale

Wetlands are valued for storing water, protecting shorelines, maintaining water quality, and recharging groundwater (Daily, 1997). Local economies in several countries depend on fisheries, reed harvesting, grazing, and recreation in wetland areas. Providing suitable habitat for fish and wildlife, wetlands foster rich biological diversity, including for threatened and endangered species. Wetlands are also valued for their recreational opportunities and aesthetics (Barbier et al., 1994). Ramsar Convention emerges as an international treaty for the conservation and loss prevention of wetlands in the world, resulting in sustainable development in all regions (Office of Natural Resources and Environment Policy and Planning, B.E. 2550). Thailand, listed number 110 as a contracting party of the convention, nominated Kuan Ki Sian wetlands of the Thale Noi Non-hunting Area in Phatthalung province as the first Ramsar site in the country. This is under the commitment to the convention that all contracting parties must designate proper wetlands in their territories to be recorded in the List of Wetlands of International Importance.

According to the National Inventory of Natural Wetland in Thailand, there are 9.26 million acres of wetlands or 7.5 percent of the country's total land. It led to the efforts of wetland prioritization and setting up measures towards the sites of national importance. The measures consist of conservation, awareness raising, study, research, and forest fire prevention. Later, the National Environment Board had a resolution to solve the increasing degradation and loss of wetlands in Thailand, which are prone to reach crisis stage. The management of wetlands requires co-operations from many bodies; thus, it is essential that conservation measures and management are aligned in the same direction. Nowadays, main factors that reduce the amount of wetlands are threats in several forms of development such as an increase in population,

ineffective use of wetlands, wetland conversion to other activities, and wetland mismanagement (Office of Natural Resources and Environment Policy and Planning, B.E. 2549-3). Although some wetlands are protected as conservation areas, the loss and problems in consequent with wetland degradation still occur. Monitoring wetlands is an urgent and crucial matter for wetland conservation in order to keep up with rapid development.

Remote sensing is a technology that enables prompt inventorying, monitoring, and assessment to benefit wetland conservation, especially for large geographic areas (Karin S.Schmidt, 2003). Satellite remote sensing helps increase accuracy of wetland detection and classification because of the spectral and spatial relationship between the light waves and physical characteristics of wetlands. Additionally, remote sensing helps reduce budget and time for examining large areas (Satellite remote sensing of wetlands, 2004). Data from satellite remote sensing and many enhancement techniques for the synthesis of wetland detection and classification have been studied and developed continuously through implementation in many wetlands around the world. In Thailand, the use of data derived from remote sensing for the study of wetlands is still limited.

Phetchaburi basin has been used for various purposes. Though stricken by flood and drought annually, it remains quite abundant (Royal Irrigation Department, B.E. 2549). Both inland and coastal wetlands exist here making it a suitable training site to be studied by remote sensing. This study focuses on Phetchaburi basin by investigating fundamental features of hydrophytic vegetation, hydric soil, and hydrology. Also, it aims to study about the enhancement and transformation of wetland satellite data, which has spectral reflection. The study includes comparison of data enhancement and transformation techniques for identifying wetlands through remote sensing technology. All of these subjects are beneficial to data acquisition, assessment, and management of wetlands, in response to Thailand's cabinet resolution and the Ramsar Convention.

1.2 Objectives of the Study

- 1) To investigate some basic fundamental characteristics of hydrophytic vegetation, hydric soil, and hydrology in wetlands of Phetchaburi basin.
- 2) To compare the enhancement and transformation techniques of satellite data from remote sensing, leading to synthesis of wetland detection.
- 3) To study the reflection characteristics from satellite data in each type of wetlands.

1.3 Conceptual Framework

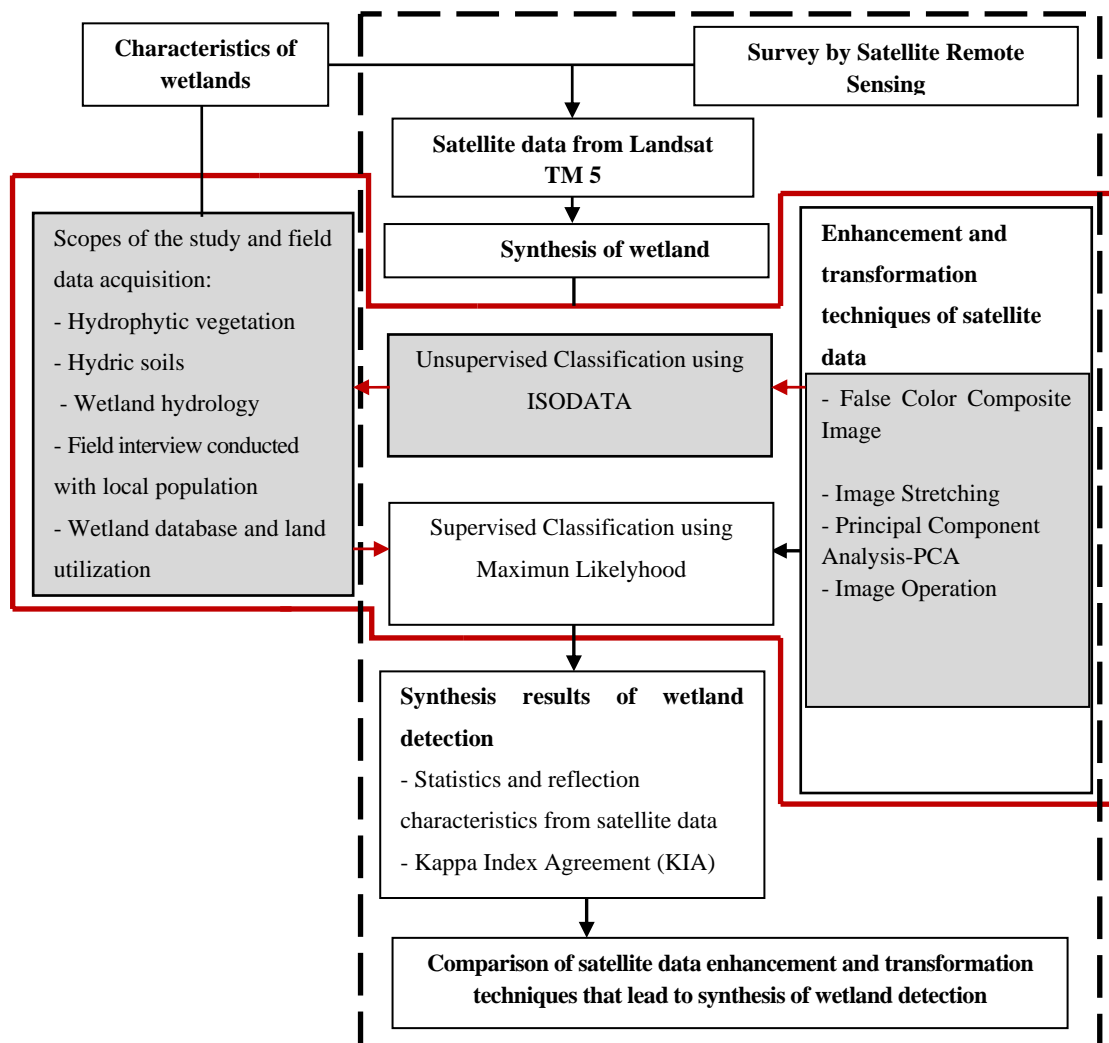


Figure 1-1: Conceptual Framework

1.4 Scopes of the Study

1.4.1 Study area

The study area is Phetchaburi basin, which extends 5,603 km² in size. It covers most parts of Phetchaburi and Ratchaburi province. The basin is vertical rectangular in shape and situated in west-east line with borders as follows:

North	Mae Klong River
South	Coastal watershed - west
West	The Union of Myanmar
East	The Gulf of Thailand

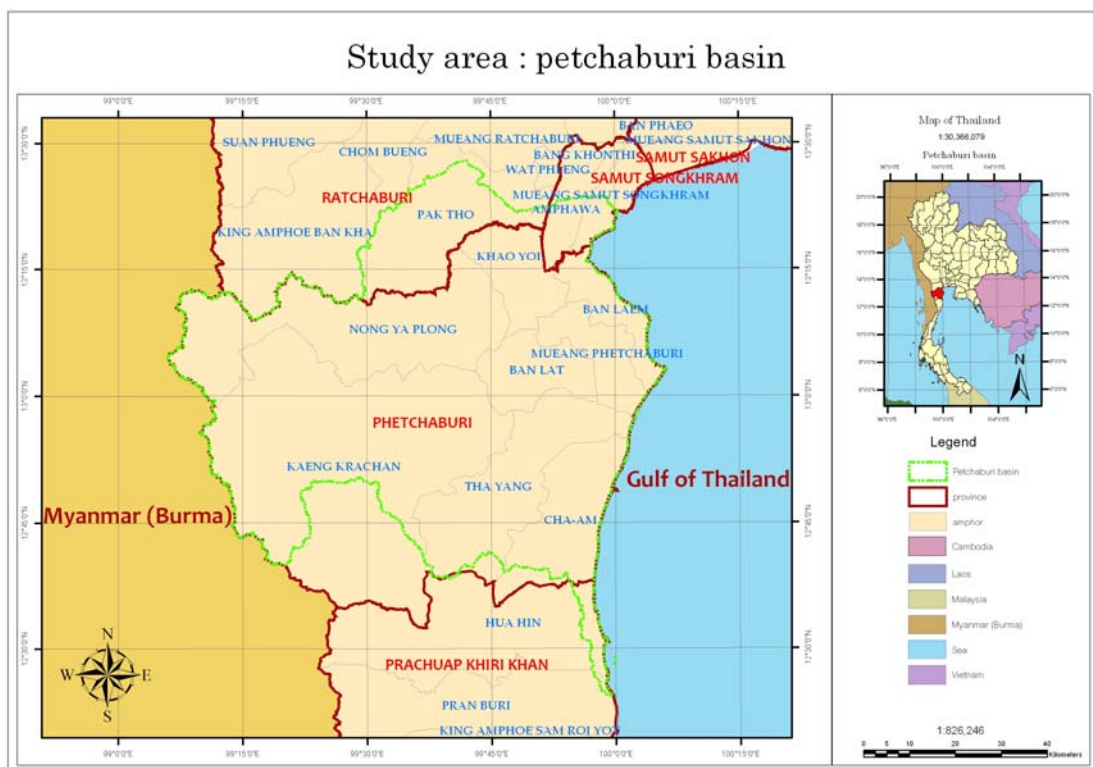


Figure 1-2: Boundaries of Phetchaburi basin

Source: Ministry of Natural Resources and Environment, and Royal Irrigation Department, 2003.

1.4.2 Population

Members of population were selected by accidental and purposive sampling, depending on opportunities and suitability of each field research. Sampling groups of population were categorized as:

1) Local population who settles and uses the land in Phetchaburi basin.

2) Government officials who are well-educated, act as community leader, or work related to Phetchaburi basin.

1.4.3 Research Content

This study is a survey research using both qualitative and quantitative data to explore in the following scopes:

1) Investigate some fundamental features of hydrophytic vegetation, hydric soil, and hydrology in wetlands of Phetchaburi basin based on field data collection.

2) Study the reflection characteristics from satellite data in each type of wetlands.

3) Compare enhancement and transformation techniques of satellite data derived from remote sensing for synthesis of wetland detection. The techniques of Image Stretching, Principal Component Analysis (PCA), and Image Operation were compared when used individually as well as when used together.

1.5 Expected results

1.5.1 Understanding of some fundamental features of hydrophytic vegetation, hydric soil, and hydrology in wetlands of Phetchaburi basin.

1.5.2 Understanding of the reflection characteristics from satellite data in each type of wetlands.

1.5.3 Knowledge in comparison results of satellite remote sensing data enhancement and transformation techniques for synthesis of wetland detection.

1.6 Definitions

Wetland means an area with 3 main characteristics: (1) the hydrology is such that there is some degree of flooding or soil saturation; (2) the vegetation is composed of plants adapted to grow in water or in a soil or substrate that is occasionally oxygen deficient due to saturation (hydrophytes); and (3) the soils are those saturated long enough during the growing season to produce oxygen-deficient conditions in the upper part of the soil, which commonly includes the major part of the root zone of plants (hydric soils).

Remote Sensing refers to long-distance survey method using satellite as a main device. It integrates spectral science, biology, mathematics, and statistics to acquire and collect satellite data.

Reflection characteristic means spectral characteristics or spectral signatures that present the relationship between electromagnetic power and land cover.

Different types of land covers give different reflection characteristics or spectral signatures.

Ancillary data refers to data that helps increase accuracy of long-distance data interpretation to identify wetlands such as topographic maps, thematic maps, aerial photographs, crop calendars, field survey, data from Global Positioning System, data from interviews, and other documents.

Data enhancement and transformation techniques are techniques used in order to enhance and transform satellite data for synthesizing. The techniques are available as ready-made software programs related to remote sensing such as image stretching, color composite image, image filtering, Principal Component Analysis (PCA), and image operation.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the literature that is relevant to research topics of 1) wetland, 2) remote sensing, 3) satellite data synthesis techniques, 4) classification of satellite data, 5) related research about the implementation of remote sensing data, and 6) Phetchaburi basin.

2.1. Wetland

2.1.1 Definition of wetland

According to the Ramsar Convention on Wetlands, 1971, wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. Wetlands may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetland." (Office of Natural Resources and Environment Policy and Planning, B.E. 2550)

- CE and the EPA (1987) defined wetlands as areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.

- National Wetlands Working Group (Canada Committee on Ecological Land Classification, 1988) defined wetland as a land that has the water table at, near, or above the land's surface or which is saturated for a long enough period to promote wetland or aquatic processes, and various kinds of biological

activity which are adapted to a wet environment including bog, fen, swamp, marsh and shallow water.

- Ministry of Environment, British Columbia, Canada (2002) defined wetlands as lands that are regularly wet or flooded, marshes, or similar areas that support plant species to be strikingly different from those in surrounding uplands. Specifically speaking, wetlands are lands with the water table under, near, or above the land's surface or which are saturated for a sufficient duration to create the oxygen-poor water and environment, which promote plant and soil development in wetlands.

- IECA (2008) defined wetlands as those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.

- Nature Serve (2008) indicated that wetland ecological systems were defined following a non-regulatory definition for wetlands, emphasizing three important attributes: (1) the hydrology is such that there is some degree of flooding or soil saturation; (2) the vegetation is composed of plants adapted to grow in water or in a soil or substrate that is occasionally oxygen deficient due to saturation (hydrophytes); and (3) the soils are those saturated long enough during the growing season to produce oxygen-deficient conditions in the upper part of the soil, which commonly includes the major part of the root zone of plants (hydric soils).

- National Geographic (2008) defined a wetland as an area in which water is presented at least for a certain time, flooded, or covered by shallow water such as a bog, freshwater and saltwater marsh, and floodplain.

- Environment Waikato (2007) indicated that wetlands are permanently or occasionally wet areas that support plants and animals specially adapted to wet conditions.

- State of Florida (2006) defined wetlands as areas with saturated soil or with fluctuation of water above or under the land surface to support plants that have adapted to grow in wet soil such as lake and floodplain.

- Washington State University (2008) indicated that the term "wetlands" can be applied to areas of land seasonally or permanently covered by

water such as lakes, rivers, bays, deltas, swamps, which are low lands, transitions, or lands inundated by saltwater and freshwater that change seasonally.

- FAO (2008) described wetlands as lands that periodically have soil saturated with water frequently enough to create a suitable environment for bird's migration, assembling, and breeding.

- Theosophical University Press (1999) defined wetlands as lands with water saturation throughout or for a period of a year to support plants and animals adapted for life in moist condition and, at times, salt-affected environment. Swamps, marshes, and floodplains are examples of wetlands.

- NRDC (2007) defined wetlands as lands (marshes or floodplains) which are saturated with water permanently or periodically to create highly rich biological diversity.

- Colorado State University (2008) defined wetlands as areas of land that contain moisture or covered by water as a regular basis such as marshes or floodplains. Other general names of wetlands are swamp, fen, and bog.

- U.S. Fish & Wildlife Service (2008) referred to wetlands as lands with water saturation or with water all or partially above the land for a period or throughout a year.

- The American Museum of Natural History (2008) referred to wetlands as low areas with permanent moisture such as floodplains or swamps.

- Water Wholesaler & Resource Planning Agency (2008) defined wetland as any land that contains water table near, above, or in the soil for at least a portion of a year. The land has vegetation adapted to wet environment.

- Princeton University (2006) stated that wetlands are low areas of land which is saturated with water.

- Encyclopedia (2008) explained that wetlands are areas of land, of which the soil is saturated with moisture, including floodplains, swamps, marshes, and bogs.

- Wiktionary (2008) defined wetland as a land that is covered mostly with water, with occasional marshy and soggy areas.

2.1.2 Wetland Classification

The Ramsar Classification System for Wetland Type (Simba Chan et al., B.E. 2548) The codes are based upon the Ramsar Classification System for Wetland Type as approved by the contracting parties. The categories listed herein are intended to provide only a very broad framework to aid rapid identification of the main wetland habitats represented at each site.

1) Marine/Coastal wetlands are categorized in alphabets A-J and ZK(a), which represent areas with shallow marine waters, marine subtidal aquatic beds, coral reefs, rocky marine shores including rocky offshore islands, sand or pebble shores, estuarine waters and estuarine systems of deltas, intertidal mud or sand flats, etc.

2) Inland wetlands are categorized in alphabets L-Z as the main code and in lower-case alphabets to identify spatial and temporal characteristics of wetlands. Wetlands in this category are permanent inland deltas, permanent rivers/streams/creeks including waterfalls, marshes, tundra wetlands, forested peatlands, freshwater swamps, geothermal wetlands, karst, and other inland subterranean hydrological systems, etc.

3) Human-made wetlands are categorized in numbers 1-9 and ZK(a), which represent aquaculture (e.g., fish/shrimp) ponds, ponds including farm ponds, stock ponds, small tanks (generally below 8 ha.), irrigated land including irrigation channels and rice fields, seasonally flooded agricultural land including pasture, salt exploitation sites, water storage areas (generally over 8 ha.), excavations, wastewater treatment areas, settling ponds, oxidation basins, canals and drainage channels, ditches. The code ZK(c) represents karst and other human-made subterranean hydrological systems.

Shaw and Eredine (1959) classified wetlands into 20 types based on geographical features, vegetations, soil moisture, and salinity in water. These types of wetlands are seasonally flooded basins or flats, inland fresh meadows, inland shallow fresh marshes, inland deep fresh marshes, inland open fresh water, shrub swamps, wooded swamps, bogs, inland saline flats, inland saline marshes, inland open saline water, coastal shallow fresh marshes, coastal deep fresh marshes, coastal open fresh

water, coastal salt flats, coastal salt meadows, irregularly flooded salt marshes, regularly flooded salt marshes, bays, and mangrove swamps.

Anderson et al. (1976) divided wetlands into 5 types:

- 1) Aquatic cover: palustrine, aquatic bed, emerged, scrub-shrub, forested
- 2) Lacustrine: Limnetic and Littoral
- 3) Riverine: open water, aquatic bed, emerged, and unconsolidated bottom
- 4) Estuarine: open water, aquatic bed, emerged, scrub-shrub, and unconsolidated bottom
- 5) Marine: open water, aquatic bed, rocky shore, and unconsolidated shore.

Cowardin et al. (1979) established a wetland classification system similar to the system of Anderson et al. However, Cowardin et al. added surface water to the class of aquatic cover and lacustrine. Also, the detail of marine wetlands were given. To conclude, Cowardin system classified wetlands as follows:

- 1) Emerged wetland
- 2) Aquatic bed
- 3) Forested wetland
- 4) Scrub-shrub wetland
- 5) Unconsolidated bottom/shore

2.1.3 Benefits and values of wetlands

2.1.3.1 Benefits of wetlands

Benefits of wetlands can be broadly grouped into 3 aspects as follows: (Office of Natural Resources and Environment Policy and Planning, B.E. 2545).

- 1) Provide natural goods to society for direct uses through consumption and for indirect uses of goods as materials to produce commercial products.
- 2) Have ecological functions, which is an indirect benefit to the communities and society

3) Possess special qualities such as biological diversity, and serve as natural and cultural heritage sites.

Different classes of wetlands in different locations provide different benefits due to the relationship between their ecology, stability, and the abundance of ecological components in physical, chemical, and biological forms.

2.1.3.2 Values of wetlands

There are three economic values that wetlands provide (Office of Natural Resources and Environment Policy and Planning, B.E. 2549):

- 1) Direct-use values: ecological functions of wetlands such as natural disaster control, and habitat for fish and water birds.
- 2) Indirect-use values.
- 3) Non-use values: biodiversity, etc.

2.1.4 Loss of wetlands

Wetlands in Thailand are mostly protected in conservation areas such as national park and wildlife sanctuary. Nevertheless, many wetlands have not been declared as conservation sites. They are facing human disturbance and various forms of development, which cause wetland reduction. The threats of wetlands are as follows: (Office of Natural Resources and Environment Policy and Planning, B.E. 2550)

- 1) An increase in population.
- 2) Ineffective, incorrect, unsuitable use of wetlands, and conversion of wetlands for other activities.
- 3) Wetland mismanagement due to the lack of knowledge in the importance, functions, and natural characteristics of wetlands among governmental and private sector, as well as civil society.

2.2 Remote Sensing

2.2.1 Process of remote sensing

Remote sensing consists of three processes, which are data acquisition, data analysis, and data utilization (Suthinee Dontree, B.E. 2549).

2.2.1.1 Data acquisition

Data acquisition is a process to acquire data from remote sensing. It comprises of main elements as follows:

1) Energy source of electromagnetic waves, both passive system derived from natural sources such as the sun and active system derived from artificial sources such as radar or sonar system.

2) Energy transfer, which is when the energy of electromagnetic waves, relying on radiation source such as the sun, receives the energy at the earth surface and reflects the energy to devices on satellite or aircrafts.

3) Reaction, which is when electromagnetic energy reacts to the atmosphere and the earth's surface.

4) Data recording system, which is a process when an electromagnetic receiving device on a satellite transmits signals to a station on the earth's surface and signals are converted into digital data or imagery.

5) Output data, both digital and image data are analyzed for further study.

2.2.1.2 Data analysis

Data analysis has two main processes.

1) Visual interpretation is an image interpretation approach based on color, shade, tone, shadow, form, size, pattern, texture and spatial components. Its principle is as same as the interpretation of aerial photographs.

2) Digital analysis and image processing is a process of analyzing and classifying data based on mathematical principles and statistics. Because remote sensing has a large volume of data in digital forms, it is inconvenient to calculate the data manually. Therefore, a computer-based system emerges to facilitate data processing. There are two methods of interpretation and classification as follows:

2.1) Supervised classification: a method of data classification which interpreters identify prototypes for the computer by choosing training areas based on knowledge of the location.

2.2) Unsupervised classification: a method of data classification which interpreters allow the computer to process data automatically. Interpreters only set classes, and the computer chooses random samples and classifies the data based on statistical criteria.

Before utilization, outputs from both methods require verification of accuracy and reliability by comparing the outputs with actual conditions or reliable data using statistical methods.

2.2.1.3 Data utilization

From data analysis and interpretation, data outputs appear in forms of maps, tables, and digital data which can be utilized for many purposes by presenting conditions of areas such as land use. The outputs aid in monitoring changes such as deforestation, flood, forest fire, urban expansion, etc. Also, the outputs can be integrated with other data using Geographic Information Systems to plan or prepare for future decisions.

2.2.2 Characteristics of electromagnetic energy

In nature, electromagnetic wave relies on sun radiation as its energy source. It is an energy form occurred as electromagnetic field that radiates in waves. Electromagnetic radiation is continuous wave of energy with wavelengths from nanometer up to several meters. The energy travels through the atmosphere in the form of waves with the speed of light, which is 299.893 km/second or 3×10^8 m/second. The movement of electromagnetic energy can be explained by the following theories and rules: (Office of National Research Council of Thailand, B.E. 2540).

Wave theory

Wave theory can describe electromagnetic radiation. Electromagnetic radiation travels as harmonic waves, which means that the waves are equally spaced with constant frequency and motion. In other words, it has the same wavelengths in a given unit of time.

Number of wave crests that pass a fixed point per second is called wave frequency (ν).

Wavelengths (λ), velocity (c), and frequency (ν) have an inverse relationship. The rule is that the shorter the wavelength, the higher the frequency, and the longer the wavelength, the lower the frequency.

Characteristics of Electromagnetic wave

Electromagnetic wave has two components: magnetic field and electric field. Both are perpendicular to the direction of propagation. Electromagnetic radiation happens when any electric charge is accelerated.

Types of Electromagnetic spectrum

Electromagnetic spectrum can be classified by wavelengths and specific attributes. It can be divided into a band or channel. Electromagnetic spectrum is composed of many regions of waves, from the shortest wavelengths such as gamma rays to the longest wavelengths such as radio waves. Electromagnetic spectrum used in remote sensing are Visible, Infrared, Microwave, and Radar. The latter two can be used with active system.

2.2.3 Types of remote sensing classified by electromagnetic spectrum and receiver

Electromagnetic spectra useful for remote sensing mostly have optical wavelengths, which refers to the spectral band of 0.34 – 14.0 μm . In respect to characteristics of each electromagnetic types and data recording devices, remote sensing can be classified into the following types (Floyd F. Sabins, 1997):

- 1) Visible and reflected infrared remote sensing.
- 2) Thermal infrared remote sensing.
- 3) Microwave remote sensing.

2.2.4 Interactions between object and electromagnetic energy

All objects reflect, absorb, transmit, and emit electromagnetic radiation in different ways. Characteristics of interactions between object and electromagnetic spectrum are called spectral characteristics. Spectral characteristics of different objects vary in terms of reflection, absorption, transmission, and emission. This is due to the

relationship between molecules and atoms of each object and the electromagnetic spectrum of a particular wavelength (Drury S.A., 1993). For instance, the reason why a leaf looks green is that the chlorophyll, a composition of leaf, absorbs blue and red spectra and reflects the green more than other spectral regions within the visible portion of the spectrum. Thus, normal leaves are seen in green color. Electromagnetic spectrum of a specific band on an object equals the total energy of reflection, absorption, and transmission (Floyd F. Sabins, 1997).

Among three interactions, reflection from objects is the most useful in remote sensing application, which is called reflectance. Reflectance of the same object varies at different spectral bands, which is called spectral reflectance. Spectral reflectance of each object has unique characteristics, which aids in interpreting and distinguishing different object types.

The reflection characteristics depend on surface's features and roughness, which can be classified into 2 modes (Lillesand & Kiefer, 2000).

1) Specular reflection occurs on surfaces that are smooth like mirrors. The incident angle equals the angle at which it is reflected. Specular reflection gives perfect reflection in the same direction, which is considered to be a theoretical reflection form.

2) Diffuse or Lambertian reflection is the reflection from objects with rough or Lambertian surface. The reflection is even and scattered in all directions.

Naturally, no objects have perfect reflection of both modes. However, there is a near-perfect reflection of either type, whether near-perfect specular reflection or near-perfect diffuse reflection, or between the two depending on surface's roughness as the main factor.

2.2.5 Interactions of electromagnetic energy with atmosphere

Both electromagnetic spectrum emitted from the sun to the earth's surface and the electromagnetic spectrum reflected from the earth's surface to the receiver must travel through the atmosphere. While electromagnetic spectrum passes the atmosphere, it interacts with the atmosphere, affecting the amount of energy from the radiation source and from the reflected radiation to be reduced, scattered, or absorbed

into the atmosphere. In this way, the energy is unable to reach the earth's surface. Interactions between the atmosphere and electromagnetic spectrum are absorption, refraction, and scattering (Lillesand & Kiefer, 2000).

2.2.6 Interactions between electromagnetic energy and land cover

Different objects on the earth's surface have different interactions with electromagnetic spectrum in terms of reflection, absorption, and transmission characteristics. Because of these variations, objects can be distinguished. The earth's covers can be classified into 3 main types, which are water, vegetation, and soil-minerals. Interaction characteristics of objects and electromagnetic spectrum are as follows: (Ravi P. Gupta, 1991).

1) Different objects have different interactions with electromagnetic spectrum. Land covers, classified as water, vegetation, and soil-minerals, interact with the same electromagnetic spectrum in different ways depending on physical or compositional attributes of the object.

2) Same objects have different interactions with different electromagnetic spectrum. Absorption may occur highly in some spectrum whereas reflection may occur highly and later be absorbed in another spectrum.

3) Same objects in different times or conditions interact with electromagnetic spectrum in different ways. For example, young and old plants interact with electromagnetic spectrum differently. Also, same type of soil with different moisture level interacts with electromagnetic spectrum dissimilarly.

4) Interactions of same objects with electromagnetic spectrum of different wavelengths can be illustrated in graph. The graph displays unique characteristics similar to human signatures. Thus, the graph is called spectral signature, which can be used for interpreting and distinguishing objects.

2.3 Satellite data enhancement and transformation techniques

Enhancement and transformation techniques of satellite data are data enhancement and data importation for operations both in each image and between images using mathematical measures and statistical methods concerning image

operation. Included here is image enhancement, which is a technique to emphasize the detail and clarity of satellite imagery, or increase contrast (Jensen, 2000). Object boundaries can be viewed more distinctly. Also, it is possible to emphasize clarity on a specific part. Relatively, it is easier to understand object types and use output data for interpretation both by further study and by visual interpretation. Also, the output can be used as criteria for nomenclature before image processing. There are numerous enhancement and transformation techniques of satellite data. Among the important techniques are image stretching, color composite, image filtering, Principal component analysis – PCA, and image ratio (Japan Association on Remote Sensing, 1993).

2.3.1 Image stretching

Image stretching is a technique to emphasize data's details by stretching the remotely-sensed image data in a given spectral band, increasing the range between the minimum and maximum values to the full limit of the computer. This technique is also called gray scale stretching or contrast stretching. It gives images better clarity in parts that the detail was previously not visible (Sabins, 1997). Gray scale stretching can be done in the following methods:

Linear stretching

Linear stretching is the simplest way to adjust the gray scale or reflectance/DN values to achieve higher gray level. It is done by setting ratio of original reflectance values and reflectance values or digital number (DN) values from 0 – 255, called the 256 gray levels (the computer limit is 8 bits), or by differentiating DN values at 256 levels. The equation is as follows:

$$DN^I = [(DN-MIN)/(MAX-MIN)]255$$

Lillesand & Kiefer, 2000: 494

DN^I = New digital number of pixel based on the stretching of minimum-maximum values at the range of 0-255

DN = Original digital number of each pixel

MIN = Minimum value of original digital number

MAX = Maximum value of original digital number

Special stretching

Special stretching only emphasizes specific reflectance of interest and ignores the rest (Lillesand & Kiefer, 2000). To illustrate, special stretching chooses only the DN range that is assumed to be the major population of the image. When image frequency is calculated, data is found to be highly clustered near the mean value and sparsely appeared near the minimum or maximum values. To study the majority of data, special stretching should be conducted.

Linear with saturation stretching

Linear with saturation stretching has the same approach with special stretching. However, to speed up the process, a selected value for stretching is set as percentage of all pixel population. Generally, image data has normal curve, which means that both tails of histogram have few data. To set values without analyzing data classification as conducted in special stretching, the percentage of pixels at the low tails of histogram is set as 0, and the percentage of pixels at the high tails of histogram is set as 255. It is like the boundary set for gray scale stretching of image data. Pixels with DN values between 33-57 (331,850 pixels) are stretched so that they are more distributed in the range of 0-255, giving clearer detail of the object in that reflectance. (Lillesand & Kiefer, 2000).

Histogram equalization stretching

Histogram equalization stretching is calculated from DN values of pixels to find color intensity that forms the image. The method starts with new calculation of gray level in the image, similar to gray scale stretching method. The equation is as follows:

$$\text{Video intensity} = [\text{DN value of pixel} - \text{Minimum DN value} / \text{Maximum DN value} - \text{Minimum DN value}] * 255$$

(Verbyla, 1995: 24)

Then, all pixels are divided by all DN values to find a result as cumulative target. After that, cumulative frequency of each DN value is compared with the cumulative target. Knowing which cumulative frequency is close to which cumulative target; new color level is assigned according to the original color level derived from the calculation of linear stretching technique. Afterwards, this new color level is used for creating image data.

Density slicing

Density slicing emphasizes the detail of satellite imagery by combining DN values of the image according to assigned intervals. The DN values of assigned interval are $\text{Maximum value} - \text{Minimum value} \div \text{Interval}$. Original DNs in each interval are combined into a single DN based on each new DN. The output can emphasize objects with same characteristics and distinguish objects with differences if the intervals are correlated with the sliced DNs and the spectral bands used are able to present the most DN/reflectance of each object type (Verbyla, 1995).

2.3.2 Color Composite

Image data examined in mono-band shows the detail of gray levels according to the band characteristics. If many aspects of data's detail are required, each individual band must be compared, causing inconvenience in studying the data together. When each band is combined using primary colors, a color composite image is produced. A color composite image displays more details than the output from individual spectral band. The primary colors used here are in the visible spectrum: blue (0.4-0.5 μm), green (0.5-0.6 μm), and red (0.6-0.7 μm). They are visible to the human eye, which is the reason why color composite images can be prepared using these 3 bands (Thailand Remote Sensing Center, B.E. 2536).

To create color composite images, each band is assigned to display one of the primary colors. Similar to looking through stained glass, objects appear in the same color of the stained glass. Or the intensity of gray scale can be altered (0-255 levels) from the maximum intensity, which is white (255), to the minimum intensity, which is black (0) to red (255-maximum intensity) to black (0-minimum intensity, the retina perceived it as black without red, but it does not mean that it is pure black.) Green (255) can be shifted to black (0), or blue (255) to black (0). When combining these three primary colors, many colors can be formed to help distinguishing different objects.

Color composite can be done in 3 forms: additive color composite, subtractive color composite, and pseudo color. Two methods to mix colors are mixing from digital data and from multispectral data. Color composite from multispectral data produces 2 types of color composite image, which are natural color composite and

false color composite. Remotely-sensed multispectral data can be prepared using color composite in many forms. Mostly, additive color composite is widely used with multispectral data.

2.3.3 Image filtering

A transformation technique of satellite data for better details is image filtering. By using filter, unwanted parts of satellite image can be deleted and some parts can be more visible. This technique aids in visual interpretation. Image filtering can be conducted with satellite data, both before and after interpretation by computer.

Filter can be applied directly to spatial data in digital format such as satellite data by an operation called convolution. Convolution is a mathematical mean to re-calculate Digital number or Reflection values of each central pixel, using all pixel values within the filter frame while scanning across the image, to be initial standard values. The initial standard values are then modified by many mathematical means such as multiplying, dividing, finding the mean, median, mode, and local standard deviation, etc. Weighting is also used in some cases (Harrison & Jupp, 1990).

2.3.4 Principal component analysis (PCA)

Principal component analysis (PCA) is a synthesis method of a large volume of data through algebraic manipulation and mechanical science. A number of data can be reduced into a smaller amount while maintaining almost all identities of data. The output of principal component analysis (PCA) is a new set of data with components constructed by a linear combination (Jensen, 1986).

Principal component analysis (PCA) used with remote sensing data is the reconstruction of components or bands that represent mass data from several original bands combined. New bands have almost the same amount of data as existed in the original bands. However, the numbers of bands or components are less, reducing the band volume to be calculated for data classification. PCA helps decrease calculation time tremendously. Meanwhile, new bands can be analyzed or formed as color composite image to improve interpretability.

2.3.5 Image operation

Image operation is a synthesis method of satellite data to increase the detail of data. In some textbooks, this method is called multispectral image ratios (Schowengerdt, 1997). Multispectral bands are used for calculation by mathematical means. It gives the output with more detail of some parts depending on the characteristic of the band used in the calculation. The well-known mathematical means employed in image operation are adding, subtracting, multiplying, and dividing multispectral image data. As for ratio calculation of multispectral image, the popular methods are vegetation index and image ratio.

Vegetation Index

Vegetation index is a value that is calculated as a ratio from spectral bands relevant to vegetation. As a result, it presents the quantitative classification of biomass from high density of vegetation to no vegetation areas. Vegetation indices help in monitoring fluctuations in vegetation and in following environmental situation in study areas. Spectral bands chosen to calculate vegetation indices are the red and near infrared portions of the electromagnetic spectrum. The red band is used because it is absorbed by the pigment in plant leaves for photosynthesis. Thus, the red gives low reflectivity. Meanwhile, the near-infrared band is not useful for the plant. It gives the high reflectivity, approximately half of the incident energy. Therefore, the ratio of both red and near-infrared bands shows the value associated with vegetation. There are many vegetation indices as follows (Schowengerdt, 1997):

- 1) Ratio Vegetation Index-RVI
- 2) Normalized Difference Vegetation Index-NDVI
- 3) Soil-Adjusted Vegetation Index-SAVI
- 3) Transformed Vegetation Index-TVI

Image Ratio

Image ratio can be calculated as a ratio or a divided value of two bands to give the result of interest. If calculating a ratio of bands related to vegetation such as Ratio Vegetation Index-RVI, the output data is about vegetation. If creating a ratio of visible spectral bands, the output data is more about objects that absorb energy such as water and shadow. If creating a ratio of short-wave infrared and near-infrared bands, the output data is more about vegetation and soil. As for the

Landsat – 5 TM satellite, the bands that were experimented are shown in Table 2.1. These methods give good results in some cases. It improves the ability to distinguish specific objects (Suthinee Dontree, B.E 2549).

Table 2-1 Image ratio and output data

Image Ratio	Output data
Visible green(2)/Visible blue(1)	Energy-absorbed objects (water, shadow)
Visible red(3)/Visible green(2)	Energy-absorbed objects (water, shadow)
Near-infrared(4)/Visible red(3)	Vegetation
Short-wave infrared(5)/Near-infrared(4)	Objects of high energy absorption(soil, mineral) vegetation, water

Source: Suthinee Dontri, 2006:157

2.4 Image classification

2.4.1 Establishing criteria for image classification

To set criteria for physical data classification, the following aspects should be considered: (Foin, 1985 and Colwell, 1983)

1) Terrain

Terrain is influential to land use system and agricultural system. It is a tool to classify land use for different activities. Hence, terrain should be taken into consideration when analyzing the study area along with satellite data interpretation.

2) Color

Colors represent the reflectance of objects, by which each band is recorded. False color composite is the most widely used technique because it emphasizes the differences of land covers most efficiently. Color-based interpretation requires interpreters to consider spectral bands that are used for forming color composite images. It is also important to consider spectral band characteristics in relation to the reflectance of each object type at the time or season of recording by remote sensing.

3) Form

Land covers come in various forms and sizes. A form happens because of physical components that appear in points, lines, or areas. Man-made objects have certain and systematic features, which may appear in points or areas. On the other hand, natural objects have uncertain features.

4) Pattern and Texture

Pattern and texture are unique characteristics of each object type in which it covers. Pattern and texture can be considered as important factors for interpretation.

5) Environment

Sometimes, interpretation of two objects based on color, pattern, texture, and form can be similar. However, when the surrounding environment is considered, the discrimination of two object types is probable. The knowledge of topography and location helps distinguishing two land uses. Nevertheless, site survey should be conducted when types of land uses or land covers are uncertain to be determined.

6) Land Cover Ratio

Land covers may separately exist in large areas such as rubber plantations, which have homogeneity. Due to land modifications by human for agriculture and settlement, lands become heterogeneous. A criterion is to consider the ratio of land covers that constitute the study area, which can be observed in field survey. When finding an object type that dominantly covers the area, it can be concluded that the area is the object type in case that the ratio matches the criterion such as more than 50% (Suthinee Dontree, B.E. 2549).

2.4.2 Image Classification

Image classification is a statistical processing to classify pixels in the study area based on shared statistical characteristics and differences of each class. The relationship displays the type of land covers. Statistically, users are able to calculate by simple calculator if the amount of population or pixel is not high. However, if there are millions of pixels in the image, manual calculation is time-consuming, inconvenient, and can be inaccurate. Therefore, the computer is brought in to help processing, giving accountable results quickly. Two main classification methods are supervised classification and unsupervised classification (Jensen, 1986). To understand image classification, the following statistical methods should be studied:

2.4.2.1 Statistical analysis of image data

Image statistics relates to electromagnetic spectrum (consider the spectral band), which associates with the reflectance of objects covering the earth's surface (water, vegetation, and soil-mineral). Statistics for primary analysis of image data are as follows (Jensen, 1986):

1) Minimum-maximum value of all pixels from each spectral band shows the range in which the data of each band falls, between the values of 0-255. If the values are near 0, it means that the spectral bands will provide data of objects with high energy absorption. If the values are near 255, it means that the spectral bands have data of objects of high reflectivity. If the range of values is wide, from the minimum of near 0 to the maximum of near 255, it means that the spectral bands have data of objects that absorb and reflect energy. These are the spectral bands that provide diverse information.

2) Arithmetic mean or the average of all values is beneficial in measuring central tendency of all pixels.

3) Median is another mean to measure central tendency. Median is the middle value of a value set when the reflectance of pixels is sorted from minimum to maximum.

4) Mode is another mean to measure central tendency using the criterion of the maximum reflectance's frequency. It is widely used with nominal scale data such as the value of information class after classification, which is the code representing land-use types, not the reflectance/DN of objects.

5) Standard deviation-S.D. is the most widely used measure to estimate the distribution. It can be calculated from the square of the difference between the reflectance/DN values of all pixels in each band and the arithmetic mean of that band.

5) Variance - σ is for measuring distribution as same as the standard deviation. It can be calculated from the mean of the total sum of deviation score square.

6) Correlation is for measuring the relation of two data sets or more. The level of correlation between data can be measured through the correlation coefficient. The correlation coefficient is between 0 to ± 1.00 . When the correlation coefficient of image data from two bands is near 1.00, it means that these two data sets are highly correlated. Two data sets may have direct correlation (positive correlation) or inverse correlation (negative correlation). If the correlation coefficient between image data is near 0, the image data of both bands shows low correlation. Thus, the correlation coefficient can be employed for examining the bands to see which bands are similar or different. It aids in reducing data volume of similar bands to be calculated and reduce classification time.

2.4.2.2 Study of statistical characteristics in the training area

Each pixel of satellite data has values in 3 dimensions, which are column (i), line (j), and brightness value (BV). Each pixel has different brightness value depending on each band, which is the vector of pixels (Suthinee Dontree, B.E. 2549).

The statistics of DN of each pixel in each spectral band consist of univariate training statistics and multivariate training statistics of each training site. The given examples are five classes of land use based on data of Landsat-5 thematic mapper in six bands (band 1-5, and 7) such as residential areas, commercial areas, wetlands, forests, water (Jensen, 1986: 190-192). After a training area is selected and statistical data of the training area are calculated by each type of land use, the statistics to identify the physical attributes of these areas are derived, ranging from arithmetic mean, standard deviation, variance, minimum- maximum value to variance-combined variance, and multivariate correlation. Statistics of training areas that are widely employed for analysis are as the following:

1) An arithmetic mean of DN value of each pixel in each training area can be used for analyzing the spectral signature to study the differences or similarities between information classes. Referring to five types of land use mentioned above, the spectral signature graph is shown in figure 2.1.

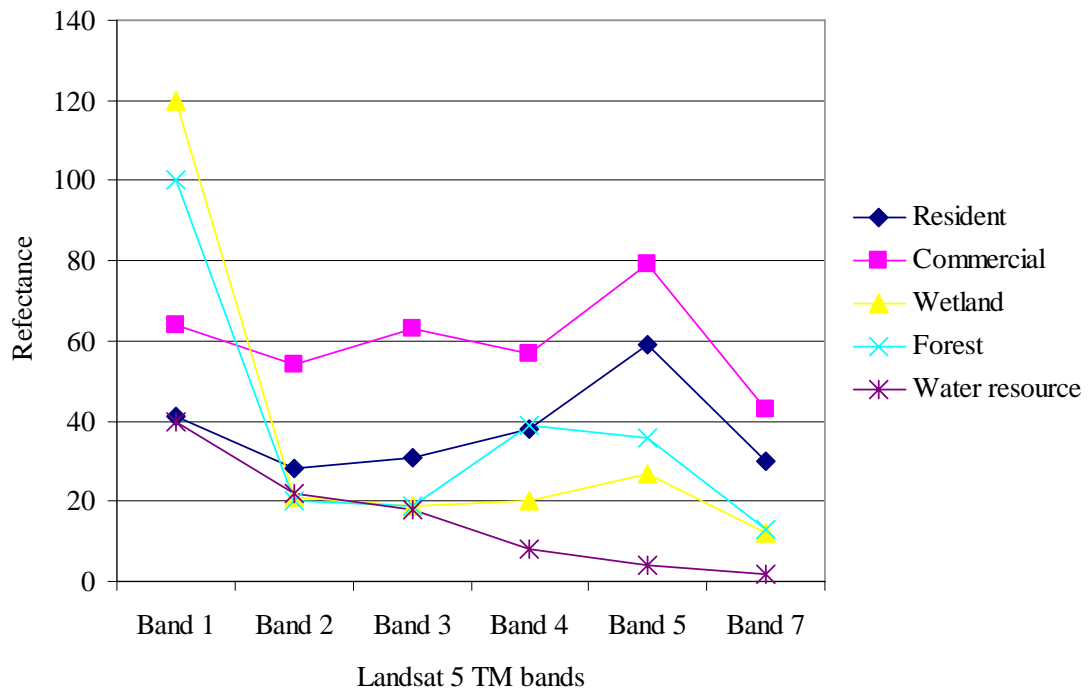


Figure 2-1: Example of spectral signatures of a training area

Source: Suthinee Dontri, 2006:206

2) Variance measures differences of data. Generally, water bodies are highly homogeneous. Thus, water bodies have the lowest variance, vegetation has higher variance, and commercial and residential areas (soil and mineral) have the highest variance because these areas are mostly heterogeneous.

3) Correlation is beneficial for selecting bands in order to use in calculation. The bands with high correlation provide the same data such as the visible bands or the mid-infrared bands. Thus, it is not necessary to use all bands, but only choose the bands with low correlation in order to decrease data volume for calculation to secure results faster.

2.4.2.3 Supervised Classification

Supervised classification is a classification method that users specify examples of information classes of interest in the image for the computer system to use. Hence, it is called supervised classification. Selected examples are statistical data that determine data characteristics, which the computer system uses for processing and classifying each pixel of satellite data into information classes specified by users as training sites (Lillesand & Kiefer, 1987). The accuracy and reliability of this classification method depend on the characteristics of training sites, whether they are adequately diverse to cover all information classes and able to represent the population of all classes. This method requires users to have thorough knowledge of study areas in order to integrate ancillary data, to do site survey, and to observe physical characteristics of each information classes as explained above (Suthinee Dontree, B.E. 2549).

2.4.2.4 Unsupervised classification

Unsupervised classification is a classification method that requires only the amount of output classes to be the initial information for the computer to process and group information classes based on the brightness of each cluster (Jensen, 1986). Users allow the computer to randomly find examples of the information classes to create mean and covariance tables. The computer classifies the information classes without example input from users. When the output is produced, users must interpret which information class refers to which object utilizing the knowledge of the study area. The method of example selection is different from supervised classification in the sampling method, especially the point sampling to find examples. Good classification output highly depends on sampling (Burt & Barrer, 1996).

2.5 Related research about the implementation of remote sensing

2.5.1 Related research about the implementation of remote sensing in Thailand

1) The Northern Center of Remote Sensing and Geographic Information System (B.E. 2543) studied and implemented data from remote sensing and geographic information system to survey and monitor the changing use of the forested land at Mae Lao-Mae Sae Wildlife Sanctuary. In B.E. 2541, ancillary data for the study was satellite data from Landsat-5 TM with the pixel size of 30 meters in six bands (band 1-5, and 7), aerial photography with the scale of 1:15,000, topographic maps with the scale of 1:50,000, geologic map with the scale of 1:250,000, and data dictionary of the Royal Forest Department. The study relied upon visual interpretation and satellite data processing to examine land uses and forest types. The enhancement and transformation techniques employed in the study were image stretching, principal component analysis (PCA), vegetation index (NDVI). Another technique used in the study included false color composite, comprising of blue-green-red from band 3-5-4 of the output data derived from gray scale saturation stretching 2.5 percent. For ground verification and reliability of satellite image data interpretation, the verification was conducted during the acquisition of sampling data concerning land-use types and after the interpretation. The study presented land-use classification in four major types and acquire information on the change of land use during B.E. 2526-2541.

2) Department of Geography, Faculty of Social Sciences, Chiang Mai University (B.E.2541) studied urban areas and urban expansion of Phitsanulok province using remotely-sensed data. Geographic Information System and satellite data processing techniques were incorporated as tools for the study. Satellite data from Landsat-5 TM, SPOT in Panchromatic system, aerial photography with the scale of 1:15,000, and Phitsanulok city map with the scale of 1:12,500 series L9013 were used. As for the enhancement and transformation techniques of satellite data to emphasize the detail, image stretching, principal component analysis (PCA), image ratio, and false color composite were employed. The comparison of all techniques showed that the best technique to emphasize image detail is principal component analysis (PCA). The principal components of the first three bands were used to form a

false color composite image of red-green-blue color. Areas with change were clearly visible. In satellite data processing, both supervised and unsupervised classification methods were used. The unsupervised method classified satellite data using Isocust and K-means. By verifying the output from data processing through field survey and aerial photography, it was found that K-means method was more accurate than the Isocust. As for the supervised classification, it was conducted using maximum likelihood with data of two periods. Then, the output was calculated using cross-tabulation tables for re-interpretation of land use classification. Supervised classification diminished errors influenced by climate change and improved data accuracy regarding land use of natural sites. Also, this method was able to distinguish urban areas very efficiently.

3) The Northern Center of Remote Sensing and Geographic Information System (B.E. 2545) implemented remote sensing and Geographic Information System to survey and monitor the change of land use in Mae Tuen Wildlife Sanctuary during B.E. 2541-2544. In the study, satellite data from Landsat MSS, topographic maps, data from field survey, and data from Global Positioning System (GPS) were used. Satellite image processing, supervised method, was employed for analyzing and interpreting the condition of forest land use. Afterwards, the output was analyzed to classify land-use characteristics. Techniques to produce the image that displays land-use characteristics from both satellites were linear stretching, geometric correction, correction verification, statistical analysis of image data, false color composite, and data classification. In classification, other supplementary factors were needed such as field survey, ancillary data for field survey, and visual interpretation. During processing, supervised classification, the most reliable technique, was used with data from both satellites. The supervised classification was performed by Idisri software program using maximum likelihood method. An overall accuracy of supervised classification is 97.99 percent, and 96.05 percent for unsupervised classification. Results were presented as maps and tables showing conditions of forested areas, change of land utilization, and deforestation. In addition, spectral distribution of objects in the study area was presented.

4) Office of the Narcotics Control Board (B.E. 2543) started implementing remote sensing to monitor cultivation of narcotic plants in B.E. 2543.

Global Positioning System and Geographic Information System were used for studying the spectral reflectance of opium cultivation obtained from Landsat and SPOT. The data used in the study included topographic maps with the scale of 1:50,000, northern region geologic maps with the scale of 1:500,000, data from Landsat in TM system and MSS path-row 131-047, and SPOT 255-311 in multitemporal and multispectral bands. To study the reflectance of opium, data from remote sensing was applied. Images were prepared for analysis by geometric correction and re-sampling pixels from Landsat data to be 10 –meter in size, which is the suitable size to study small opium fields. Bi-cubic interpolation method was utilized to stretch the pixels into desirable sizes. Then, false color composite technique with red-green-blue using band 4, 5, and 7 was used to adjust and crop specific parts of the image that were not of interest for field data verification. The study also used principal component analysis (PCA) which only analyzed PC1 and PC2. Vegetation index was calculated and then classified by the maximum likelihood method. Field data was incorporated for verification. Data analysis process was adjusted by a new selection of study areas based on the criteria of ancillary data relevant to opium cultivation (at the height above 800 meters) and visual interpretation of opium fields' physical characteristics associating with the spectral bands. The above techniques yielded satisfactory analysis results. To obtain reflectance values, output data of the same study area from visual interpretation and computer interpretation were laid together overlapping. Satellite data from SPOT in multispectral and panchromatic modes were used to verify the accuracy. Then, values from opium cultivation found in the field survey were compared with data interpretation from the same year (e.g. B.E. 2541). As a result, the reflectance values of the same area can be concluded as the reflectance values of opium.

2.5.2 Related research about the implementation of remote sensing in the study of wetlands

1) Townsend and Walsh (1998) studied the capabilities of Landsat TM and SAR for detection of floodplain of the Roanoke River, North Carolina. The imagery from Landsat TM had limitations because it failed to identify water level under the shrubs during shedding period. The imagery from SAR was

derived from JERS-1 and ERS-1. The bands and the angle of radar transmission were decreased, which determined signal depth that penetrated through the surface. Longer wavelengths had higher capability to penetrate through the shrubs, especially when the wavelength of the spectral bands was longer than the leaves. ERS-1 used a sensor that received shorter signal than C-band, while JERS-1 used a sensor that received longer signal than L-band. Differences of flooded and unflooded areas were distinctly distributed in the image from JERS-1. As for the ERS-1 image, it was still useful to detect differences of flooded and unflooded sites despite the less distinction of differences when compared to the image from JERS-1.

2) Kushwaha et al (2000) evaluated ERS-1 SAR and IRS-1B LISS-II data for distinguishing mangrove wetlands in the coastal region of West Bengal, India, which is usually cloudy, especially during monsoon season, in order to find the algorithm for filtering and enhancing image data for wetland detection. The detection capability of terrain features in SAR image had limited scope due to the presence of noise. This study evaluated various filters for the best combination in noise suppression and ground detail enhancement. The results indicated that the filter with a 5 x 5 pixel window size was the most efficient. The transformation of gathered data and the output image were compared, taking the intensity-hue-saturation (IHS) transform into consideration. Therefore, the image was constructed by increasing spatial and spectral resolution since each component of the specified condition could be separated without affecting others. False color composite of SAR data from pre-monsoon, monsoon and post-monsoon improved wetland classification. According to daily SAR data, false color composite of SAR and IRS-1B LISS-II using near-infrared IRS (band 4) instead of SAR data could discriminate wetlands most successfully. The study advised that the results depend on study area, with the condition that noise in radar data must be suppressed and imagery must be enhanced to distinguish wetlands efficiently.

3) Gluck et al. (1996) evaluated image interpretation of color infrared aerial photography at three scales. They also evaluated the classification of digital data from Landsat TM in mapping wetlands in northwestern Ontario. Wetlands consist of marshes, open swamps, covered swamps, and forested wetlands. The images

from TM in green and red near-infrared and mid-infrared during spring (April) and summer (August) were used with principal component analysis (PCA). The first three components were utilized for unsupervised ISODATA classification with 250 clusters. The first component (PC1) highlighted the differences of vegetation brightness values. The second components (PC2) highlighted moisture differences. The third components (PC3) distinguished wetlands from uplands. Band section and slope of band section in each of the 250 clusters were plotted in graph, which aggregated them into 40 classes. With ground reference data and each plotted band section in these 40 classes, they were then reduced into 11 wetland classes. Landsat TM data were used for classification of wetlands. The overall accuracy at pixel level was 72 percent when comparing wetland classification to ground reference data. When aggregating classes with common characteristics, the overall accuracy increased by 81 percent. The advantage of using an unsupervised classification is that it preserved spatial resolution of pixels. If a supervised approach had been used, wetland classes might be omitted or aggregated too much since the analysis could not connect finer scale ground reference data to the satellite imagery.

4) Hewitt 1990 conducted a study to produce accurate maps of riparian areas in shrub and pasture eco-systems of Eastern Washington with Landsat-TM data. March data were classified by an unsupervised method using band 2, 4, and 7. Band TM7 was obtained to discriminate water and locate riparian zone. Band TM2 was chosen because it was uncorrelated with TM7 and would provide complimentary data for classification. Finally, band TM4 (near-infrared) was chosen because the reflectance peak of green vegetation occurs in this band. Data of the training site were specified based on field data acquisition. During data acquisition, positions of image were chosen to identify spectral signatures related to 16 vegetation classes in the study area. The study area classification was executed by algorithm of maximum likelihood. The original 16 classes were aggregated into 3 classes of water, riparian, and others. An accuracy was assessed by random sampling and comparison with aerial photography. An overall mapping accuracy is 81 percent (Hewitt, 1990). To conclude, the accuracy was improved by obtaining multitemporal data, an image from winter or spring when the water level was highest and an image from summer when vegetation

had fully developed leaves. Besides, buffer zone should be used to create larger pixel boundaries as a distance from water class in order to improve wetland classification.

5) Hodgson et al. (1987) used a hybrid classification known as “guided clustering” with Landsat TM data during late-spring (May) to identify the habitat of wood stork in wetlands and lowlands. Image from spring provided significant separation of wetlands. Firstly, 6TM bands, including infrared bands, were transformed. The transformation was executed by reducing 6TM bands into 3 spectral features, which corresponded to brightness, greenness, and moisture level. Then, three procedures of guided clustering were used to classify the brightness, greenness, and moisture level: 1) identified multispectral clusters of wood stork foraging habitat; 2) determined spectral signature of other land cover classes; and 3) merged the two sets of signatures together to classify the study area using 32 clusters in minimum distance classification of 12 subscenes. In subscene classification, wetlands were sometimes confused with forests. Thus, new signatures were created for confused classes resulting in a final set of 37. After that, a minimum to mean distance classification technique was implemented to the total scene of the areas. An accuracy was assessed by low altitude aerial photography and recorded locations of 39 known wood stork foraging sites. A classification accuracy was 74 percent for wood stork foraging. An inaccuracy of the unclassified occurred because the TM image had low resolution so that small wood stork sites could not be identified.

6) Johnston and Barson (1993) evaluated Landsat TM data for inventorying and classification of wetlands in Australia. The research aimed to create a topographic map using simple density slicing of bands that were related to physical parameters such as vegetation indices (biomass/productivity), mid-infrared (soil, moisture), and visible blue (water depth/turbidity), which may be as effective as more complicated statistical classification methods. Multitemporal imagery (winter/spring and summer) provided information of seasonal variability in hydrology and vegetation. A threshold value of Landsat TM band 5 was used to give information of area scope and location of wetlands. All pixels below a threshold value of TM5 were mapped as wetland areas. A threshold value was classed empirically. It depended on the types of wetlands and conditions at the time of image acquisition, which emphasized the temporal importance in data acquisition. Data from a density slice of

Landsat TM band 5 were able to identify 95 percent of marshes, but only 50 percent of freshwater meadows. They had little success mapping between different vegetation types and concluded that the classification of satellite imagery was more related to vegetation density, intensity, and moisture status than to species distribution. According to the study, satellite remote sensing was perceived as complimentary techniques for mapping process. Satellite data can provide an overview of a large region and update information on water regime and vegetation.

7) Huguenin et al. (1997) used subpixel processing to classify bald cypress and tupelo gum wetlands in Georgia, South Carolina. Satellite data in May (after spring) were classified. Large scale (1:7,000) color IR aerial photography was used to identify conditions of bald cypress and tupelo gum in four study areas, sometimes including individual trees, for the training sites (two sites) and test data (two sites). NAPP photography was used outside the study areas. Field survey was employed to identify homogeneous stands and mixed stands. Traditional classification methods (ISODATA clustering, maximum likelihood, minimum distance to means) were utilized. The minimum distance to means was the best traditional method. Subpixel processing was able to identify tupelo gum with 91 percent accuracy, and bald cypress with 89 percent accuracy. On the other hand, the minimum distance to means classification gave 85 percent and 71 percent accuracy respectively.

8) Sader et al. (1995) implemented simple GIS model to classify wetlands in Maine. Ancillary data included soil moisture, maps of NWI, DEM, and hydrography. The model was compared to an unsupervised classification, a tasseled-cap transformation, and a hybrid classification of unsupervised classification of cluster statistics and supervised maximum likelihood classification. Landsat TM imagery was used. TM band was highly correlated; thus bands 3, 4, 5 were chosen to reduce the number of data bands. These bands were chosen because previous research found them to be optimal for classification of wetlands. Rule-based model consists of four hierarchical layers. Each layer used the GIS data and assigned weights depending on whether the criteria were met or not. Each pixel was assigned a value, based on whether it was forested or unforested by unsupervised classification. Weights was assigned according to whether it was a Palustrine in NWI, whether the soil was hydric, then whether the slope was 5 percent, and finally whether it was in a three pixel buffer

around the NWI hydric soil polygon. Hydric soil and slope were the most important variables in the model. Rule-based GIS classification did not imply higher accuracy than a hybrid classification. Both approaches had overall accuracy of 80 percent. The output would be better if a hybrid classification had been used in GIS model, instead of the unsupervised classification.

9) Lunetta and Barlogh (1999) used a simple rule-based GIS model to classify wetlands and vegetation types in uplands of Maryland and Delaware. They used two dates of Landsat TM imagery, June 11, 1988 (leaf-on) and June 20, 1986 (leaf-off). Imagery was chosen after a precipitation event during a normal precipitation year. Gray-level thresholding techniques of April Landsat TM band 5 imagery were used to define area and distribution of saturated and unsaturated soil. Density slices of band 5 were the most efficient to separate wetlands from uplands. The classification started with the imagery to identify spectral signature. Then, the cluster statistics were brought into maximum likelihood classification. Color infrared aerial photography at three scales, topographic maps, and land utilization maps were used to identify land cover classes. Classes constituted of wetlands (forests, shrubs, perennial plants, and agricultural area) and uplands (forests, shrubs, herbaceous plants, agricultural areas). Finally, GIS analysis was used to reclassify hydric soil areas into wetland classes, unsaturated soil classes, and upland classes. The classification method using image data from two dates gave higher accuracy (88 percent, comparing to 69 percent) than from the single image date.

10) Fuller et al (1998) used the basic process of GIS after classification to improve wetland classification. A wetland map in Sango Bay, Lake Victoria, Uganda was created using data from Landsat TM. Field data was used for finding the training area through supervised classification. However, after classification, some errors were easily identified that which land cover type would be mapped based on the surrounding environment. Thereby, he created a mask for cultivated, built up classes, and filtered out the wetlands that their classes were unidentified. The accuracy is 86 percent.

11) Munyati (2000) monitored change in wetlands and floodplains in southern Zambia with Landsat MSS and TM imagery. All images were received by the same sensor due to budget limitation. Mid-infrared band from Landsat

MSS was chosen because wetlands are easily separated from surrounding uplands by this range. The variations due to vegetation phenological change were limited by the utilization of near-anniversary images. All printed satellite images currently available were imported into field survey to help gathering ground reference data. GIS determined 87 areas of the same cover type. A hybrid classification was used. Field locations were collected and nominated symbols for classification. Areas with similar spectral signature were then regrouped and assigned new symbols, giving the final result of 15 classes. The rest were classified in a supervised classification with the accuracy of 73 percent. Other three images were classified by the same method. The output created 15 classes in reference image and maintained in the original image. In the original image, there were no classes that had not been appeared in the final image. 15 detailed classes were reduced into 6 broad classes to improve accuracy. This method was employed because in the study of change compared to classified images, it is crucial to obtain high classification accuracy in each image. The change found would replace classification errors, which were unidentified.

12) Houhoulis and Michener (2000) developed a rule-based model to detect wetland change and to improve NWI data of forested and herbaceous wetlands interspersed within a predominantly agricultural landscape, which created classification difficulties and confusion. First, satellite multispectral imagery derived from SPOT were classified into 20 classes using unsupervised classification technique. These classes were aggregated into 6 coarse categories: 1) water, 2) wet soil, 3) forest, 4) shrub, 5) plantation, and 6) bare soil. Pixel vector modulus was calculated in this formula: $(\text{Sqrt}(b_1^2 + b_2^2 + b_3^3 / N))$, which represented the Euclidean distance of each pixel from the origin in multidimensional space. NWI data was used as a zonal layer, and the mean modulus and majority of land cover values for each NWI polygon were calculated. Statistics generated from NWI system and majority land covers were to find the rule base in wetland change. Each wetland type has pixel vector modulus values of less than 40, the least of NWI system. Thresholds for detecting wetland change were developed by adding standard deviation (SD) to the mean of modulus histograms plotted by NWI system and majority land covers. An overall accuracy of wetland change was 90 percent for the rule-based system, with the dominant NWI systems accuracy's (PFO, PEM, PUB, PSS, PAB) ranging from 87 to 94 percent.

Developing rule-based criteria can initially be labor intensive. In this study, a standard deviation threshold of the mean modulus value is the key logic rule, which can be applied quickly. The pixel vector modulus may prove useful for other studies on change detection because it is easy to calculate, able to capture spectral variations, reduce data volume, and save processing time.

13) M.Y. Jollineau and P.J. Howarth (2007) undertook mapping of inland wetlands using hyperspectral imagery to see boundaries of heterogeneous inland wetlands, vegetation communities, and local species. Also, they identified vegetation types in adjacent uplands to enable mapping using aerial photography. The 4-meter hyperspectral Compact Airborne Spectrographic Imager (CASI) was used. Two classification algorithms, the maximum likelihood classifier (MLC) and the spectral angle mapper (SAM) were applied to CASI data acquired over an inland wetland complex. Application of the MLC algorithm to all bands of the CASI data produced better classification results than use of the SAM. Using the MLC, 10 classes were identified with an overall accuracy of 92%. This approach permitted differentiation between areas of shrub-dominated vegetation communities, floating aquatic communities, emerged aquatics and shallow open water. In the SAM classification, image-derived spectral endmembers were generated. Wetland classes identified were shrub-dominated wetlands, floating aquatic vegetation communities, shallow open water and moderately turbid shallow open water. Upland vegetation types were accurately mapped with both algorithms. It is concluded that high-resolution hyperspectral data can provide information needed by wetland managers about inland wetland plant communities and their dominant species.

14) Kitiya Nilaphat and Yongyut Trisurat (B.E. 2549) applied Geo-informatics for wetland classification in Bangkok and vicinity to create database and to classify wetlands into five layers using primary and secondary data for analysis. The primary data consisted of five layers: 1) land use, 2) water regime, 3) water body size, 4) water salinity, and 5) river and stream network. The first three layers were derived from visual interpretation of Landsat-5 TM during rainy and drought season. Layers of water salinity and river and stream network were gathered from field survey and buffered from hydrology, respectively. The secondary data included three layers: 1) study area boundary, 2) irrigation area, and 3) soil group. Spatial data were

analyzed by GIS software based on Wetlands Classification System. The results showed that there were 15 subclasses of wetlands, comprising an area of 1,505 km².

2.6 Phetchaburi basin

Phetchaburi basin is 5,603 km², which can be divided into 3 sub-basin; the Upper Phetchaburi River, the Huai Mae Prachan River, and the Lower Phetchaburi River. The Phetchaburi basin is situated among areas of Phetchaburi province, Ratchaburi province, and Prachuap Khiri Khan province. The basin is vertical rectangular in shape situated in west-east line (Royal Irrigation Department, B.E. 2549).

Terrain

The basin has its western area sloping down into the east. Hills are situated in the basin creating plains. In the west of Phetchaburi basin, there are mountains, which are the origin of important rivers. The middle areas of the basin are floodplains. Phetchaburi river runs through Kaeng Krachan Dam & Reservoir, and Phetchaburi Dam. Coastal floodplains are found in the eastern lower part of the basin.

Climate

Phetchaburi basin has the average temperature at 27.7 °C. The average relative humidity is 75.3 percent. The minimum wind speed in the area is 2.6 kn, the maximum is 30 kn, the average is 2.8 kn. The average cloud cover is 5.9. Pan evaporation can be measured at 1,648.5 mm. Rainfall in Phetchaburi basin is ranging from 900 mm. to 1,400 mm, with the annual average of 1,063.8 mm. The drainage areas total 5,603 km². The average natural runoff is 1,384.7 million cu.m.

Soil

Areas in Phetchaburi basin can be classified into four types according to soil types suitable for different vegetation types.

- 1) Soil suitable for rice and other crops
- 2) Soil suitable for agronomy, olericulture, pomology, and perennial plants.
- 3) Soil unsuitable for general plants.
- 4) Soil unsuitable for all plants.

5) Wetland, mine, and others.

Land use

Phetchaburi basin is utilized for many purposes:

1) Cultivation is accounted for 37.12 percent of the basin, distributing in the eastern and middle areas. In the basin, there are 33.59 percent of field crops, 14.46 percent of pomology and perennial plants, 50.99 percent of rice field, and 0.96 percent of olericulture.

2) Forested areas are 52.24 percent of the total area. Forests are clustered in the mountainous western part of the basin, which can be divided into 0.08 percent of wildlife sanctuary, 58.03 percent of national park, and 41.89 percent of forest conservation areas.

3) Residential areas are 1.51 percent of the total area. They are dense in the coastal area, sparse in the middle area, and very sparse in the mountainous western area.

4) Water source is 0.80 percent of the total area.

5) Other uses total 8.33 percent of the basin.

Problems in Phetchaburi basin

Main problems in Phetchaburi basin are as follows:

1) Flood: two kinds of flood occurred in this area; a) flood occurred in the upper basin from heavy rainfall and flash flood that exceed the drainage capacity, causing overflow in the main rivers. Other factors are water flow obstruction causing by transport infrastructures and inadequate spillway; and b) flood occurred in floodplains, where the main rivers are shallow with low drainage capacity.

2) Drought: the problem arises due to a long period of dry spell, making cultivation fields outside irrigation areas suffer from the drought, short of water for consumption, cultivation, and other activities.

2.7 Summary of literature review

According to the literature review, physical features of wetlands yield spectral relations evident in satellite data as the relation between electromagnetic energy and land covers, which is the principle of satellite remote sensing. There are many enhancement and transformation techniques used with satellite data to identify objects and land cover types. The techniques are image stretching, color composite, image filtering, principal component analysis, and image operation. The outputs from enhancement and transformation techniques give statistical values of image data, which present physical features and spectral signature of each object type. The application of statistical analysis helps improve classification accuracy. The classification methods by computer have supervised and unsupervised approaches. The supervised classification provides higher accuracy, but requires thorough knowledge of interpreters.

The application of satellite data for wetland identification in Thailand has not been widely studied. There were only the studies of wetland classification. Most satellite data from remote sensing used in Thailand have been used for detection of narcotic plants, agricultural plants, natural hazards, land and coastal change, and urban expansion. Internationally, many studies on wetlands were conducted with the aim to create wetland maps as well as monitor the change of wetlands. LandSat TM and SAR data were widely used because the TM band is high in correlation, and the SAR gives better data in unfavorable climate and can detect water level under shrubs by its radar. However, most studies employed ancillary data such as topographic information, contour lines, soil series, thematic maps, etc. Choosing satellite data to be used is truly important because the distinction for wetland classification in different season may vary. Multitemporal data produced higher classification accuracy. Furthermore, essential enhancement and transformation techniques of satellite data before the synthesis: noise reduction, filtering, and intensity-hue-saturation (IHS) transform improved the spatial quality and spectral details. Widely used enhancement and transformation techniques that gave high accuracy of wetland detection were image stretching, principal component analysis (PCA), and image operation. As for the supervised classification, the most popular and accurate approach was maximum likelihood classification. In unsupervised method, ISODATA was widely employed.

Other techniques to improve accuracy were buffer setting to enlarge pixel boundary from water class, hybrid classification, and subpixel processing. Also, GIS model was used to assist in identifying wetlands from the classification of rule-based GIS and simple rule-based GIS using ancillary data concerning hydric soil, NWI and DMI maps, and hydrogeology. The model was compared with several classification methods and integrated with statistics of partial substitution equation of calculation statistic equation to classify wetland types, which helped improve the accuracy.

Field survey and field data acquisition were crucial to the study because they provide more classification accuracy. Data management and data selection were important factors affecting the classification as well. If some bands gave high detection accuracy, it was adequate to use only some bands that were necessary for wetland management and able to provide common details. However, this approach needed techniques with more calculation time, more complicated equation, and more ancillary data.

CHAPTER III

MATERIALS AND METHODS

According to objectives and scope of study about the use of satellite data with data enhancement and transformation techniques for wetland detection in Phetchaburi basin, guidelines of study methods can be drawn as follows:

3.1. Data used for this study

In this study, 2 types of data were used.

1) Data from remote sensing or satellite data from Landsat 5 TM

2) Ancillary data increases accuracy of wetland detection and technique comparison, comprising of geographic information database of Prachuap Khiri Khan and Ratchaburi province, data of Phetchaburi basin areas and borders, data of wetlands in central and eastern region, topographic maps with the scale of 1:50,000 from Royal Thai Survey Department, data from Global Positioning System (GPS), reference data of hydrophytic vegetation, soil, and hydrology, data from field survey, and data from field interview conducted with sampling population.

3.2. Materials

3.2.1 Materials used in field study

- 1) Global Positioning System: GPS
- 2) Topographic maps of Phetchaburi and Ratchaburi province, covering Phetchaburi basin.
- 3) Color composite images from Landsat TM, band 3-5-4 (blue-green-red).

- 4) Maps of route and field survey location
- 5) Notebook and field survey's recording form
- 6) Camera
- 7) Compass
- 8) Test kit and Munsell Color Book
- 9) Shovels
- 10) Measuring tapes
- 11) Plummets
- 12) Square meters string to collect vegetation types
- 13) Reference books of hydrophytic vegetation, hydric soil, and hydrology in wetlands

3.1.2 Processing materials

- 1) Computers
- 2) Data processing programs
 - ENVI program version 4.1 for comparison of wetland detection techniques, consisting of comparison techniques as follows: Principal Component Analysis, image ratio, image stretching with supervised classification using maximum likelihood.
 - ArcGIS program for mapping and presenting results of data synthesis.

3.3. Data collection

Table 3-1 Data collection and expected outcomes

Data collection	Expected outcomes
Fundamental data collection	Secondary data
A. Study and ask permission for data from Royal Irrigation Department and Office of Natural Resources and Environmental Policy and Planning	A. Data of areas, borders, resources, and conditions of Phetchaburi basin and wetlands in central and eastern region of Thailand
B. Study and ask permission for data from Environmental Quality Promotion Department and Land Development Department	B. Database files of Phetchaburi, Ratchaburi, and Prachuap Khiri Khan province
C. Study and ask permission for data from Geo-Informatics and Space Technology Development Agency	C. Data of remote sensing, remotely sensed data management, and image files of Landsat TM
D. Study and ask permission for data from Royal Thai Survey Department	D. File of topographic map covering Phetchaburi basin

Table 3-1 Data collection and expected outcomes (cont.)

Data collection	Expected outcomes
Field data collection	Primary data
E. Analyze Landsat TM image using false color composite technique in band 3-5-4 (blue-green-red) with unsupervised classification. Then, it was overlaid with road data and land use data from the database	E. Maps of route and field survey location to access wetlands in Phetchaburi for field survey planning
F. Specify 100 location points in the study area using UTM coordinate system to link with Global Positioning System (GPS) in field work	F. Obtain maps showing location and distribution of the study area (100 points) covering wetlands in Phetchaburi basin. 50 points are the training area, another 50 points are the testing area.
G. Go on the field survey employing field survey's recording form, observation, and evaluation of wetlands by researcher	G. Collect wetland data from the actual site of all study points about vegetation, soil, and hydrology of Phetchaburi basin
H. Record interview conducted with local population and officials	H. Obtain data of land utilization and the condition of the actual site at the time of recording by satellite in order to assist in image interpretation

3.4. Analysis of satellite data processing

3.4.1 Image preparation

Image preparation consists of image subset before geometric correction, geometric correction, and image subset after geometric correction.

1) Image subset before geometric correction is to select only the study area in order to reduce data volume for calculation. It can be conducted by reading coordinates of the study area starting from the coordinate of the first row/line and the first column/pixel, and the last row/line and the last column/pixel.

2) Geometric correction is a method of image rectification by creating relationship between the rectified image and reference image coordinate systems. Data needed to be rectified is assigned new coordinate according to reference image coordinate system. In this study, image-to-map correction was conducted. Images of systematic correction were rectified using non-systematic correction. It was the image-to-ground geocorrection using polynomial function. Ground Control Point (GCP) was identified based on the coordinate in the topographic map or real coordinate from Global Positioning System (GPS). This would be the data for mathematical calculation to compare coordinates of image and geographic system. The calculation employed the least square method. Accuracy could be determined by the order of polynomial function, and the number as well as the distribution of GCPs.

Calculation of geometric correction has 2 processes as follows:

2.1) Geometric coordinate transformation between raw images (x',y') and geographic coordinates (x,y) used geometric correction incorporating linear equation to find new coordinates. It is called spatial interpolation, which has the following formula.

$$x' = a_0 + a_1x + a_2y$$

$$y' = b_0 + b_1x + b_2y$$

x' = Coordinate of column of rectified image

y' = Coordinate of row of rectified image

x = Coordinate of column of image before rectification

y = Coordinate of row of image before rectification

2.2) Accuracy of rectification was verified through the calculation of least square regression method. Root mean square error - RMS_{error} from each GCP was calculated to determine accuracy. The formula is as follows:

$$RMS_{error} = \text{Root} [(x' - x_{orig})^2 + (y' - y_{orig})^2]$$

$RMS_{error} = \text{Accuracy value of GCP}$

$x_{orig}, y_{orig} = \text{Coordinate of GCP in image before rectification}$

$x', y' = \text{Coordinate of GCP in rectified image}$

RMS_{error} shows accuracy of GCP coordinates, compared to reference coordinates. It accepts variation of ± 1 pixel. In this study, Landsat TM image of 30-meter pixel size was used.

2.3) Image subset after geometric correction was conducted. When new coordinates were assigned to be geographic coordinates, the image slightly deviated to the right side, causing a black area that contained no reflectance values and existed outside its original boundary. This might be confusing with data in its original boundary. Thus, image subset must be conducted again.

3.4.2 Enhancement and transformation techniques for synthesis

Data synthesis was undertaken through image data enhancement and transformation techniques. The same data preparation processes and ancillary data were assigned. Techniques were compared to see which one has highest efficiency in wetland detection. Three groups of techniques for comparison are as follows:

- Image stretching by linear stretching.
- Principal component analysis (PCA).
- Image operation or multispectral image ratio using Normalized Difference Vegetation Index-NDVI, and image ratio.

The study undertook 3 main processes:

1) Each technique was applied to image data. Then, it was imported to wetland detection and classification.

2) Two best techniques from the first process were incorporated to synthesize data for further detection and classification of wetland.

3) All three techniques were incorporated to synthesize image data for wetland detection and classification.

3.4.3 Image data processing

Before processing, field survey was conducted to acquire primary data of the study area and to understand the area and wetlands. Then, all collected data and ancillary data were processed. According to wetland classification, land use, and characteristics of Phetchaburi basin, wetlands were classified into 5 types for processing: 1) water source, 2) hydrophytic vegetation, 3) shrub, 4) forest in wetland, 5) farm in wetland. Beyond these classification types were areas not considered as wetlands. Non-wetland areas were determined by the criteria of land use type based on field survey and Geo-Informatics database of Land Development Department. Afterwards, the data were processed and enhanced as follows:

- 1) Image stretching by linear stretching.
- 2) Principal component analysis (PCA).

3) Image operation or multispectral image ratio using Normalized Difference Vegetation Index-NDVI, and image ratio of 3 ratios consisting of red visible band (band 3) to make ratio with green visible band (band 2) in order to see areas of high absorption and water, near infrared (band 4) to make ratio with red visible band (band 3) to see vegetation areas, and shortwave infrared (band 5) to make ratio with near infrared (band 4) to see areas of high absorption and overview. Then, the outputs were imported to supervised classification, which had the processes and details as follows:

3.1) Select training areas to represent wetlands in the study area. Training areas were wetlands distributed all over the study area representing characteristics of those wetlands. In a training area, more than 30 pixels must be obtained to be the statistical representative of normal distribution. Training areas should be selected only in the areas occupied by objects of the same color so that they were homogeneous samples. Training areas were drawn in rectangular shape to save time and to prevent problems from occurring when statistical values of each training area from each band were calculated. When the boundary of training areas showing all types of land use was obtained, samples were classified by each band used in processing. Statistical data of pixels in training areas of each band were analyzed to evaluate the reliability as a good representative of each sample selected from each band.

3.2) Statistical analysis of training areas was conducted, considering minimum - maximum value of land use types, reflectance mean, variance, combined variance, and correlation.

3.3) Statistical methods were used to classify data type. In the study, maximum likelihood classification was employed based on the principle of Bayes Maximum Likelihood Classification with the following formula:

$$\text{when } p(i/f) = p(f/i)p(i)/p(f)$$

$$p(f) = \sum_i p(f/i)P(i)$$

$p(f/i)$ Function of probability before data classification into class i

$P(i)$ Probability before classification

$P(i/f)$ Probability after classification

$P(f)$ Total probability before classification of each pixel

Criteria is if $P(i/f) > p(i/f)$ when all $j \neq i$, the pixel will be classified as class i

3.4) Image classification was conducted with all images by maximum likelihood classification using ENVI program version 4.1. Accordingly, data were classified as determined earlier and the number of files was reduced into one output file. Classification result had brightness values in numbers based on the number of class determined earlier, which were the representative value of each class in nominal scale.

3.5) Classification accuracy or accuracy assessment.

3.5.1) To examine the confusion of data classes, classified data were overlaid on areas with actual data of land use from the testing area. It could be analyzed based on the confusion matrix to compare classified areas with actual conditions and to assess accuracy based on real conditions. The number of pixels in the training area representing accurate land use as their actual conditions and the number of pixels classified as other land use classes varying from the actual conditions were both counted to create the confusion matrix. Good classification has the least data confusion, which can be checked using the confusion matrix. At the data cell of

the same class in both axes, the number of pixels must be highest, compared to all pixels. Or the confusion matrix has correctly classified data highly on the diagonal of the matrix, indicating mostly correct classification. Confusion of data classified into other land use classes is called omission error. On the other hand, confusion of data incorrectly included in the class is called commission error.

3.5.2) To verify classification accuracy, ground truth was conducted by obtaining sampling data which were well-distributed across the study areas to represent classes. Areal sample was conducted, and then the contingency table was created. The contingency table showed comparative results of classification, both with accuracy and errors. The evaluation employed probability of statistics and acceptable error rate. In this study, omission error, commission error, mapping accuracy, and over mapping accuracy were analyzed using the following formulations:

- Omission error

$$= \frac{\text{[Pixels of the class classified as other classes]}}{\text{All pixels of the class based on actual condition}} \times 100$$
- Commission error

$$= \frac{\text{[Pixels of other classes classified as the class]}}{\text{All pixels of the class based on actual condition}} \times 100$$
- Class accuracy

$$= \frac{\text{[Pixels of the class correctly classified based on classification and actual condition]}}{\text{All pixels of the class based on actual condition}} \times 100$$
- Overall accuracy

$$= \frac{\text{[The sum of pixels from all classes correctly classified based on classification and actual condition]}}{\text{All pixels used as samples in testing}} \times 100$$

Besides the calculation methods above, Kappa Index Agreement (KIA) according to the principle of Rosenfield and Fitzpatrick-Lins can be conducted by the following formula:

$$K = \frac{\text{(observed accuracy - chance accuracy)}}{\text{(1 - chance agreement)}}$$

Here

- Observed accuracy refers to ratio obtained from the sum of correct pixel numbers in row i and column i , or correct pixel numbers in the diagonal of the matrix, divided by the number of all pixels (Proportion of agreeing units- p_0).

- Chance agreement refers to the sum of all pixel numbers in row i multiplying with all pixel numbers in column i , then divided by the multiplying result of all rows and columns (Proportion of units for expected chance agreement- p_e).

3.6) Image reclassification means the classification output being reclassified. It emphasizes wetland identification in 5 layers: physical characteristics, radiometric characteristics of the same class, data confusion based on confusion matrix, distribution of data class compared to actual conditions, and shared major characteristics.

3.5. Data analysis and presentation

3.5.1 Analysis of spectral reflectance

Based on the statistical values of training areas, average reflectance/DN value of each pixel in each wetland training areas was used to analyze the spectral signature. It aimed to study the differences and similarities of data classes by creating spectral signature graph. Then, it was analyzed according to the theory of reflectance/DN value.

3.5.2 Comparative analysis of enhancement and transformation techniques for wetland identification

Classification comparison can be measured by Kappa Index Agreement (KIA) in wetland classification of each enhancement and transformation technique.

The data output were presented as the summary table of reflectance and statistical values, table of technique comparison and accuracy in wetland identification, graph of reflectance/DN values of wetlands in various bands, photographs of wetlands classified by each technique. Also, image output using techniques of image filtering and smoothing were presented. The pixel numbers of

each wetland class were multiplied with the area of 1 pixel (30 meter), giving the area in square meter. Then, the area in square meter was divided by 1,000,000 sq.m., giving the area in square kilometer. The area in square kilometer was multiplied with 625, giving the area in Rai. Afterwards, the remotely-sensed data format was transformed into vector format and raster to be saved in .LAN, .img, .TIFF, or .bmp compatible with remote sensing software for analysis and for integration with other sciences or databases.

CHAPTER IV

RESULT AND DISCUSSION

4.1 Fundamental characteristics of Wetland

Field survey is performed for studying on basic characteristics of wetlands and field data collection perspectives of wetlands vegetation, soil science and hydrology for being training area of satellite image classification and sampling area for data verification after classification. From field survey, the result is found that the current situation of wetlands area (B.C.2009) and land cover are considerably changed from the previous satellite data in B.C.2007. Moreover field survey operation which is delayed from January to February and March is beyond satellite image record period (January). The delay therefore affect field survey spots specified at planning stage. They have to be revised according to actual field operation. Therefore, survey spots have to be shifted from existing ones to new spots observed in the field with 195 spots for data collection. The study result of Petchaburi River Basin wetlands on some basic characteristics of vegetable, soil science, and hydrology are presented as follows.

4.1.1 Open-water Wetland Characteristics



Figure 4-1: Open-water Wetland

For open-water wetland characteristics, the study involved in forty (40) spots of open-water wetlands. Determined as inundation all year round, its water depth is of 1-50 meter. They consist of river, pond, swamp, reservoir, creek, marsh, storage dam, and sea. These wetlands are classified into 2 categories: fresh water and sea water. Concerning fresh water wetlands, this type of plant community is found that they are depended on water depth such as submerged plant (“Sa Rai Hang Kra Rork” or Hydrilla or Hydrocharitaceae, moss, and other algae species); floating plants (“Jork” or water lettuce or Pistia stratiotes, “Nae Daeng” or Mosquito fern or Azolla pinnata, “Phak Waen” or water clover or Marsilea crenata Presl, “Phak Bung” or morning glory or Ipomoea aquatica Forsk, “Phak Kra Ched” or Water mimosa or Mimosaceae, “Phak Tob Chawa” or Water Hyacinth or Eichornia crassipes, “Phak Prab Bai Kwang” or Commelina benghalensi, “Phak Prab Bai Khaeb” or Commelina diffusa); Emerged Plants (water lily or Nymphaea lotus Linn., “Thoob Ruesi” or Cat-tail or Typha angustifolia L., “Kok” or Egyptian payrus or Cyperus papyrus L.) and Marginal Plants (“Born” or Elephant ear or Colocasia esculenta (L.) Schott var. aquafiliis Hassk, “Prong” or Sago palm or Cycas revolute, and “Song” or Sesbania or Sesbania javaica Mig.) Regarding soil property of study area, most of soil texture is clay. Some of them are loam and sandy soil. Soil color of land that is close to seashore is light gray to dark gray with high organic matter of 40-70 %. Concerning sea water of open-water wetlands, it is found that plant community is strand vegetation. Mainly are perennial trees that are “Son Tha Lae” or Queensland Swamp Oak Horsetail Tree or Casuarina equisetifolia J.R. & G. Forst., “Ma Kham Thet” or Manaila Tamarind or Pithecellobium dulce Benth., “Mai Ya Rab Yak” or sensitive plant or Mimosa pigra L. For understory vegetation, most of them are “Phak Bung Tha Lae” or beach morning glory or Ipomoea pes-caprae (L.) R.Br, “Mai Ya Rab” Mimosa Pudica or Biophytum sensitivum DC., “Kra Bong Phet” or or and “Khloo” or Indian Marsh Fleabane or Pluchea indica Less. They often found in sandy soil or sandy clay or on sand ground with high organic matter of 20-50 %.

4.1.2 Emerged Wetland Characteristics



Figure 4-2: Emerged Wetland

For emerged wetland characteristics, the study involved in sixty-three (63) spots of emerged wetlands. Determined as inundation all year round, its water depth is of 1-50 meter. The areas constitute the similarity of plant community of “*Thoob Ruesi*” or Cat-tail or *Typha angustifolia* L., “*Kok*” or sedge or *Cyperus imbricatus* Retz, and “*Bua*” or American lotus or *Nelumbo Lutea*. Mainly “*Thoob Ruesi*” or Cat-tail is the most dominant plant species of the wetland area. Other two most dominant species in some zones within the wetland are “*Kok*” or sedge and “*Bua Sai*” or Egyptian white water-lily or *Nymphaea lotus*. In some areas, Cycad, fern, “*Mai Ya Rab Yak*” or sensitive plant or *Mimosa pigra* L. are found. Furthermore, there are more plants spreading and found such as “*Phak Bung*” or morning glory or *Ipomoea aquatica* Forsk, “*Teen Tuk Kae*” or climbing fig or *Ficus pumila*, “*Dok Rak*” or crown flower or *Calotropis gigantea*(Linn.) R.Br.ex Ait., “*Ma Rah Khee Nok*” or Basism Pear or *Momordica charantia* Linn., “*Ta Khob*” or East Indian plum or *Flacourtia jangomas* (Lour.) Ransch., “*Kra Thin Thung*” or Yellow eyed grass or *Xyris indica* L.(family: Xyridaceae) including some climbing plants vines. Influenced by seawater (with salinity more than 0), the wetland areas are therefore found the salt tolerance plants that like sandy soil, mangrove soil. Such species are “*Khloo*” or Indian Marsh Fleabane or *Pluchea indica* Less, “*Jark*” or Atap palm or *Nypa fruticans* Wurmb., coconut etc. Considering to soil characteristic, the wetland area is plenty of clay with fossil. The soil color is gray to blackish with high organic matter of 40-70%. Only

some zones contain sandy clay, loose soil, and sandy soil with high organic matter of 20-30%.

4.1.3 Scrub Wetland Characteristics



Figure 4-3: Scrub Wetland

For scrub wetland characteristics, the study involved in twenty-six (26) spots of scrub wetlands. Determined as inundation in some seasons, its water depth is of 0-1.50 meter. The areas mainly constitute the plant community of scrub wetland of “*Mai Ya Rab Yak*” or sensitive plant or *Mimosa pigra L.*, grass, “*Kra Bong Phet*” or cactus, “*Khoi*” or Tooth brush tree or *Streblus asper Lour.* The other perennial trees are also found within the area: “*Khloo*” or Indian Marsh Fleabane or *Pluchea indica Less.*, “*Ma Kham Thei*” or Manaila Tamarind or *Pithecellobium dulce Benth.*, “*Por*” jute or *Corchorus sp.* and Eucalyptus. “*Thoob Ruesi*” or Cat-tail or *Typha angustifolia L.*, “*Kok*” or Egyptian payrus or *Cyperus papyrus L.*) are also spreading and found in some zones. The zones where are inundated all year round are found nearby seashores with salinity more than 0. In Ban Laem District, the plant community characterizes more mangrove vegetation than the other study plots. From the investigation, most of soil is clay, sandy clay, loose soil and sandy loam with brown to gray and high organic matter of 20-50%.

4.1.4 Farmland Wetland Characteristics



Figure 4-4: Farmland Wetland

For farmland wetland characteristics, the study involved in forty-three (43) spots of farmland wetlands. Land use pattern is mainly for rice farming and shrimp culture. Rice or *Oryza sativa L.* is the dominant plant species of the wetlands. Influenced by high salinity, the salt tolerance plants are found in the rice farming and shrimp culture zones e.g. “*Khloo*” or Indian Marsh Fleabane or *Pluchea indica Less.*, and “*Cha Khram*” or seablite or *Suaeda maritima Dum.* etc. Determined as inundation in some seasons, its water depth is of 0-5 meter depending land use pattern. Almost of soil is mainly brown to dark gray with high organic matter of 20-50%. Few is sandy clay, sandy soil and loose soil with yellowish, brown to red with less organic matter of 20-30%.

4.1.5 Forest Wetland Characteristics



Figure 4-5: Forest Wetland

Eighteen (18) study spots consist of mangrove forest located on the Eastern part. Forest wetlands size are relatively changed by tidal effect 0-3 meter. Plant community is composed of “*Samae*” or olive mangrove or *Avicennia marina* Vierh. “*Kong Kang*” or Red Mangrove or *Rhizophora mucronata* Poir, “*Tabun*” *Xylocarpus granatum*, “*Jark*” or Nipa Palm or *Nipa fruticans* Wurmb, “*Ta Tum Ta Lae*” or Blind your eyes or *Excoecaria agallocha* Linn., “*Pho Tha Lae*” or Portia Tree or *Thespesia populnea* (L.) Sol. ex Correa, “*Khloo*” Indian Marsh Fleabane or *Pluchea indica* (L.) Less., and “*Cha Khram*” or seablite or *Suaeda maritima* Dum. Moreover, “*Kok*” or Egyptian payrus or *Cyperus papyrus* L. and “*Thoob Ruesi*” or Cat-tail or *Typha angustifolia* L. can be found with “*Samae*” or olive mangrove or *Avicennia marina* Vierh in some areas especially on Ban Laem District, Cha-Am District, and Muang Districts. This wetland type is always influenced by tidal effect that is submerged all year round. Soil texture is clay, mud, and some of them are clay based with sandy soil. Salinity is high with 5-35 % and high organic matter of 50-70 %. In the western part is massive forest wetlands especially in Kaeng Krajan and Nong Ya Plong Districts where are not affected by sea water. The plant community is Deciduous Dipterocarp Forest that consists of “*Teng*” or Siamese Sal or *Shorea obtusa* Wall. ex Blume, “*Rang*” or Burmese sal or *Shorea siamensis* Miq., “*Daeng*” or Burmese Ironwood or *Xylia xylocarpa* var. *kerrii*, “*Eucalyptus*” and “*Makhatae*” or *Sindora siamensis* Teijsm. Ex Miq.

Plant community of Mixed Deciduous forest consists of “*Sak*” or Teak or *Tectona grandis* L.f., “*Daeng*” or Burmese Ironwood or *Xylia xylocarpa* var. *kerrii*, “*Pradoo*” or Burma Padauk or *Pterocarpus indicus*, “*Makha Mong*” or *Azelia xylocarpa*, Bamboo or *Cephalostachyum pergracile*, and grass or *Imperata cylindrica* Beauv. This forest part is seldom flooded in rainy season of some years with water overflow. Therefore, the zone is not determined the wetland study area. At the end of westward part is massive forest that is not determined for field survey spots.

For other areas besides wetland areas, the field data is collected for 5 spots of salt farm located adjacent to Farmland Wetland. Salt farm’s characteristics are quite the same as wetland areas with the period of intake sea water to salt farm and waiting for salt sedimentation. After sea water is drained, salt crystal is found. In this period, salt farm characteristic is absolutely different from Farmland Wetland. Salt farm is

counted for temporary water logging with water depth of 0-0.25 meter. Some plants are found in salt farm such as “*Chacram*” or *Suaeda maritime*, grass, and few “*Samae*” or olive mangrove or *Avicennia marina Vierh.* Soil texture is clay and mud mixed with little silt. Soil color is gray green, light brown gray, and brown. Its color is always found said the color with gray green mottled. Organic matter is lower than 20% but salinity is higher than 100%. Most of salt farm are located on Ban Leam and Muang Districts. Actual field survey area is also found land cover and major land use e.g. building, residence area, urban area, reinforced concrete road, laterite surface road, golf course, opened area, water logging on opened area, field crop (pineapple etc.), garden crops (Palm, Mangosteen, Coconut etc.), deciduous forest, evergreen forest, deteriorate forest for agriculture purpose, dumping area, detour route for residence area access and internal agriculture land etc. Such other areas are recorded as general data of Petchaburi Province for making understanding of wetlands’ land cover for entire watershed. It can facilitate for satellite image interpretation and classification of wetlands from other land uses.

4.2 Image processing with enhancement and transformation techniques

4.2.1 Landsat 5 Thematic Mapper (TM) data with studied image

Landsat 5 TM is resource surveying satellite has data as many bands which combine for earth surface material studying. Attribute of satellite data as the following:

4.2.1.1 Visible bands are human eye awareness with reflected energy peak at 0.5 micrometers. Visible band are 3 major bands: Blue visible wave, Green visible wave and Red visible wave that are create all colors on human eyes. Visible bands are effectively reflected in high absorption material such as water or moisture. Theses bands provide water component clearly in the image thrust it can be used for water sediment, estuary, shoreline and general of water.

4.2.1.2 Infrared bands are beyond human eye awareness but each band can be used by differences sub benefit. Near infrared band has the benefit for vegetation reflectance because its radiance not used by vegetation in photosynthesis

difference from visible band, that why this band has reflectance from vegetation up to 50 percent. For Short wave infrared band and middle infrared band are effectively reflected in high reflectance material benefit to study in soil feature, soil material, land use and minarets.

Spectral bands on Landsat 5 TM image data have 30 meters resolutions or pixel size, means 1 pixel of sterilizes data showed average 30 meters on ground area. But band 6 (TM6) is thermal infrared, wave length 10.4-12.5 micrometers, is average 60 meters different spectral resolutions from the other.

This study used Landsat 5 TM sterilizes data with 6 bands are 30 meters spectral resolutions. Landsat 5 TM data, 6 bands are information as below:

- Band 1 (TM1) is Blue, wave length 0.45-0.52 micrometer.
- Band 2 (TM2) is Green, wave length 0.52-0.60 micrometer.
- Band 3 (TM3) is Red, wave length 0.60-0.69 micrometer.
- Band 4 (TM4) is Near infrared, wave length 0.76-0.90

micrometer. This band has benefit to separate vegetation soil and water.

- Band 5 (TM5) is Short infrared, wave length 1.55-1.75 micrometer. This band has benefit to separate land use, soil feature and minarets.

- Band 7 (TM7) is Middle infrared, wave length 2.08-2.35 micrometer. This band has benefit to separate land use, soil feature and minarets

The study area, Phetchaburi basin is in 2 sheets of sterilized data which are details as below:

1) Sheet g129051

Columns	: 129	min.X	: 536003.5
Row	: 51	max.X	: 752803.5
Ref.system	: utm-47n	min.Y	: 1345265.5
Ref.unit	: meter	max.Y	: 1537265.5
Unit dist.	: 1		

Taken on 5th, January 2007

Table 4-1 Statistic data of Landsat 5 TM data, sheet g129051

	Minimum	Maximum	Mean	Median	Mode	SD
Band 1	54	193	87.85	88.00	87.00	6.57
Band 2	19	111	35.95	35.00	32.00	5.03
Band 3	14	151	34.45	31.00	27.00	9.64
Band 4	11	146	40.00	39.00	16.00	24.03
Band 5	3	254	48.16	34.00	11.00	41.39
Band 7	1	239	23.17	14.00	6.00	21.30

2) Sheet g130051

Columns : 130 min.X : 475374.5

Row : 51 max.X : 587324.5

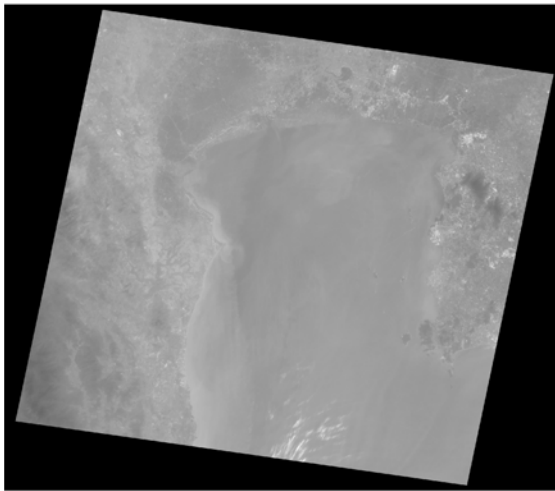
Ref.system : UTM Indian 1975 min.Y : 1344441.5

Ref.unit : meter max.Y : 1522366.5

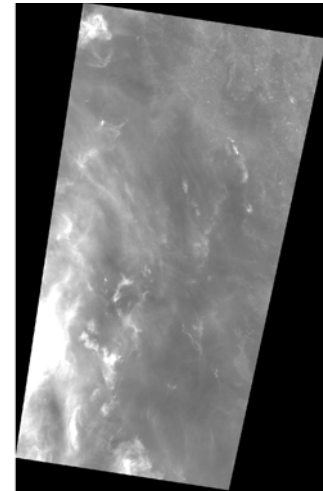
Unit dist. : 1

Taken on 30th, January 2007**Table 4-2** Statistic data of Landsat 5 TM data, sheet g130051

	Minimum	Maximum	Mean	Median	Mode	SD
Band 1	58	255	85.80	80.00	74.00	20.74
Band 2	22	120	36.66	34.00	29.00	10.01
Band 3	17	136	35.51	32.00	27.00	12.33
Band 4	13	137	71.28	71.00	69.00	13.26
Band 5	7	234	62.18	60.00	55.00	19.27
Band 7	3	171	24.02	22.00	19.00	10.26



Landsat 5TM, Sheet g129051
Path 129 ,Row 51
Taken 05-01-2007



Landsat 5TM, Sheet g130051
Path 130 ,Row 51
Taken 30-01-2007

Figure 4-6: Original, 6 band combination of Landsat 5TM 2 sheets

4.2.2 Data preparing with image mergence and clipping

After the images imported process, 2 sheets images with all bands need to prepare by merged the overlap area for the result image that cover all study area, Phetchaburi basin show as Figure 4.7.

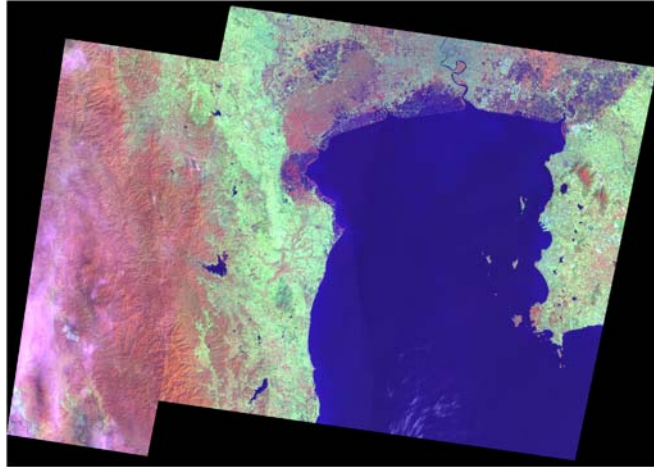


Figure 4-7: Merge image of Landsat 5 TM imagery sheet g129051 and sheet g130051

After finished mergence, the result image has clipped with Phetchaburi basin boundary to confine data on studying, convenience for wetland detection or classification processing and easy for Kappa Index Agreement calculation by program. Result of clipping show as Figure 4-8.

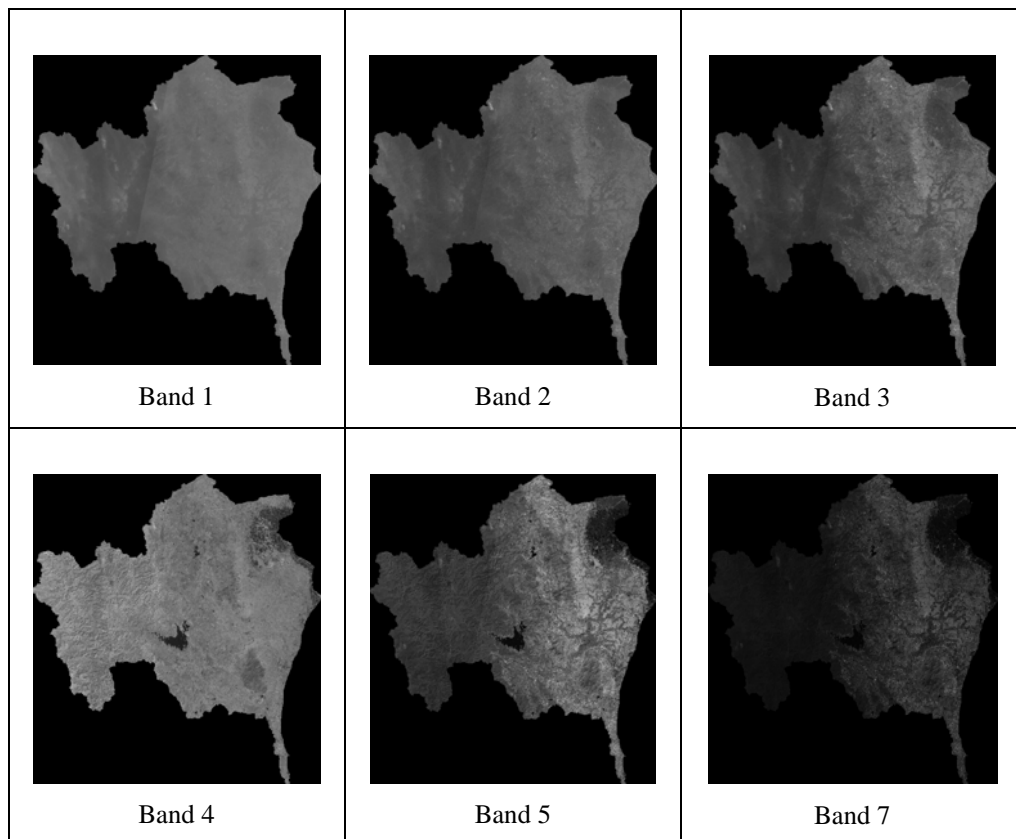


Figure 4-8: Clip image of Landsat 5 TM imagery six bands

Image data are separated by each band wave length for 6 bands are Visible bands (Band 1, 2, 3) and Infrared bands (Band 4, 5, 7). For wetland detection studying by supervised classification method on this study, all 6 bands have to combine for training area selection by program user or image interpreter.

4.2.3 False color composite

After data preparing used basic technique, false color composite to enhance image detail. This study use additive color composite with 3 major colors are red green and blue to emphasize initial image to be input data for image classification processing with other enhancement and transformation techniques. Band component of additive color composite as follow:

Red major color (R): replace with Band 4 which high effective with vegetation reflection so this band helps to separate vegetation material from the other material. The high density of vegetation showed as intensive red color area in image and light red color area in image in order showed decreasingly vegetation.

Green major color (G): replace with Band 5 which high effective with high reflection material so this band helps to separate soil and open field material from the other material. High reflection material showed as light green in image.

Blue major color (B): replace with Band 3 which high effective with water and moistures reflection material so this band helps to separate wet area and water material from the other material showed as blue color in image. False color composite with 3 bands additive color show the result as Figure 4.9.

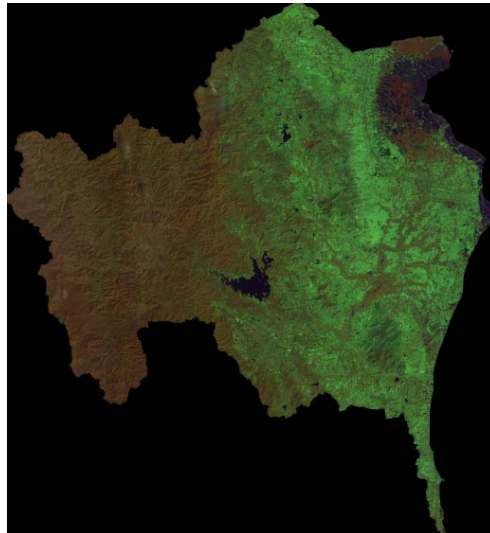


Figure 4-9: False color composite image of Landsat band 453 (RGB)

4.2.4 Image operation with Normalized Difference Vegetation Index

Image processing with Image operation with Normalized Difference Vegetation Index-NDVI technique perform by calculation of image operation between band 3 and band 4 for Normalized Difference Vegetation Index. The result of this technique is only one band with pixel value from -1 to 1. The value get close 1 is high value with high vegetation density showed as white color area in image. When values are 0 or 1 and get close -1 to 0 is low value with low vegetation density showed as black color area in image. Result of Normalized Difference Vegetation Index-NDVI showed as Figure 4-10.

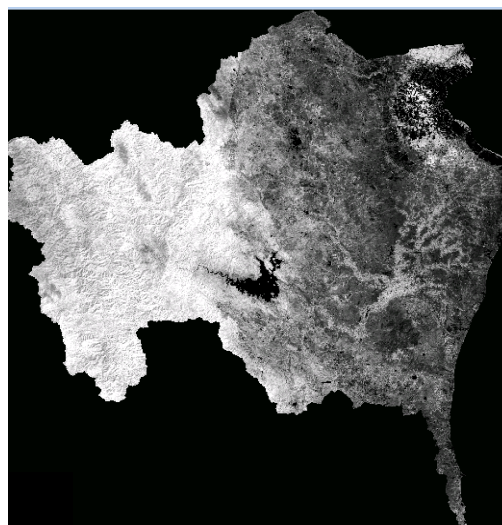


Figure 4-10: Image operation with Normalized Difference Vegetation Index-NDVI

4.2.5 Image stretching with linear stretching

Image processing with image stretching with linear stretching is gray scale adjustment 0 to 255 levels of image brightening to differentiate brightening to be 256 levels. The result image was the initial image for wetland classification. Result of linear stretching showed as Figure 4.11.

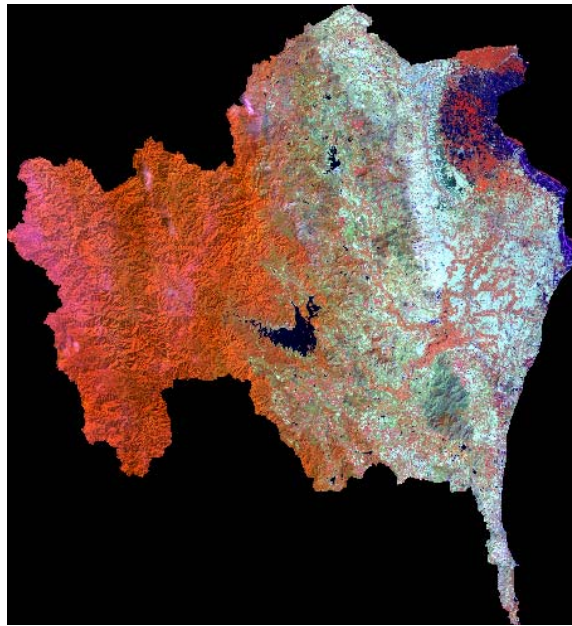


Figure 4-11: Image stretching: linear with False color composite band 453 (RGB)

4.2.6 Image with Principal Component Analysis-PCA

Image processing with Principal Component Analysis-PCA is the method that concluded great number of all data then decrease data with keeping almost of image or data principal component. Software was analyzing principal component of image automatically. The result image was the initial image for wetland classification. Result of principal component analysis-PCA showed as Figure 4-12.

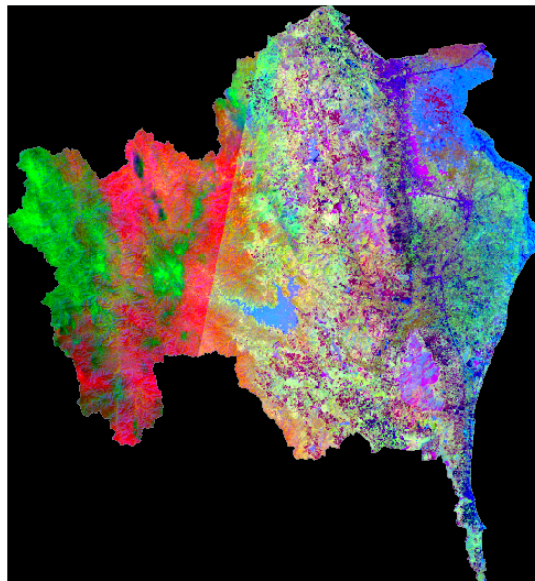


Figure 4-12: Image with Principal Component Analysis-PCA

4.2.7 Supervised classification

A supervised classification then performed to classify unknown area by the method called maximum likelihood with the training area that user define base on field study data to input in the program operation. Each pixel was justified to the class considering from the highest probability computed by the program imagine. Landsat 5 TM sterilize data of Phetchaburi basin area are detected and classified into first 24 classes then conclude to be 9 classes are 8 wetland classes for 5 wetland type and the other class. On maximum likelihood classification found that Image operation with Normalized Difference Vegetation Index-NDVI can not classify because of the real reflectance of each pixel was calculated to -1 to 1 for new reflectance value by equation of Normalized Difference Vegetation Index-NDVI. However Image stretching with linear stretching and Image with Principal Component Analysis-PCA were classified with the clear result so these two techniques were combine, the result as the Figure 4.13 then input to classification process.

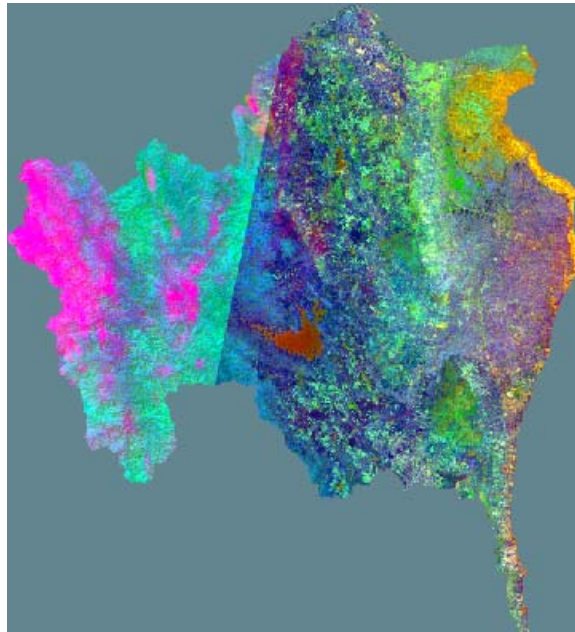


Figure 4-13: Image with linear stretching and PCA

Wetland classification processing provided to experiment hypothesis that difference classification results on maximum likelihood method with Linear Stretching, Principal Component Analysis-PCA and Linear Stretching combined with PCA. Figure 4.14 to Figure 4.17 showed result maps of all post maximum likelihood classification with original image also with each enhancement and transformation techniques.

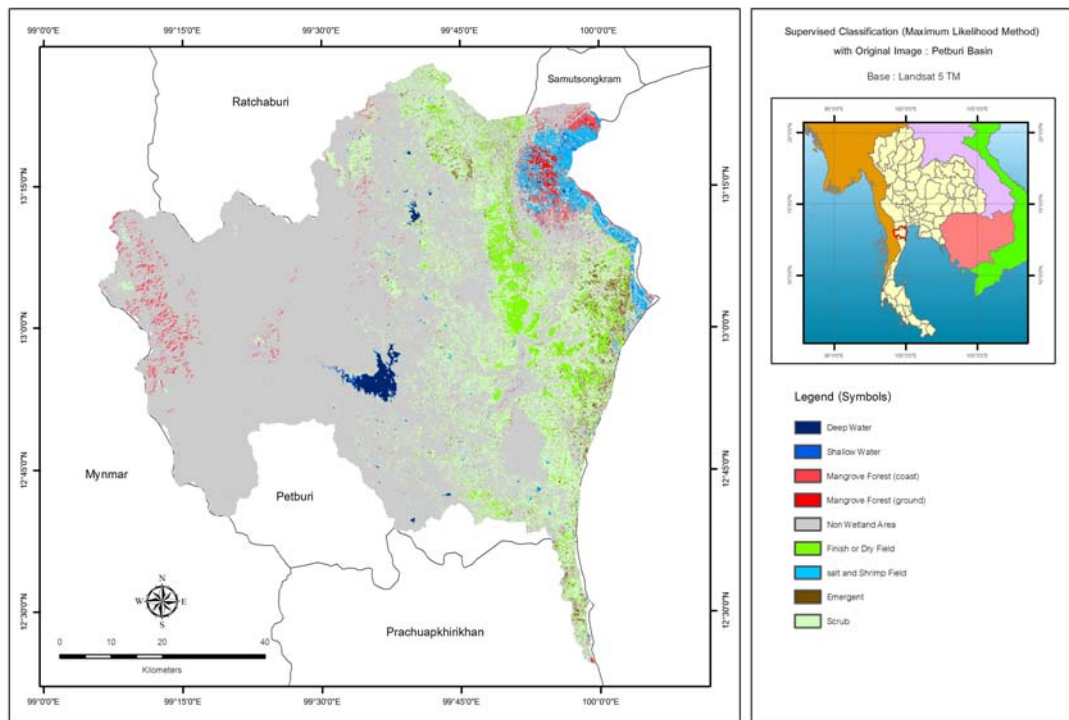


Figure 4-14: Maximum likelihood classification with original image

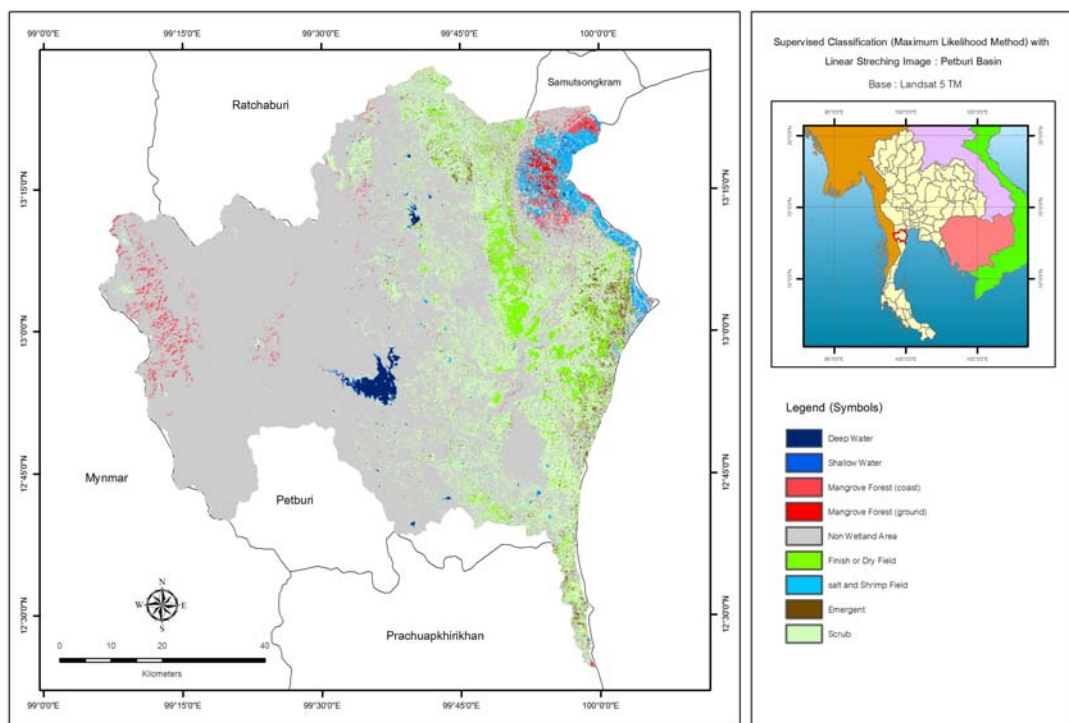


Figure 4-15: Maximum likelihood classification with linear stretching

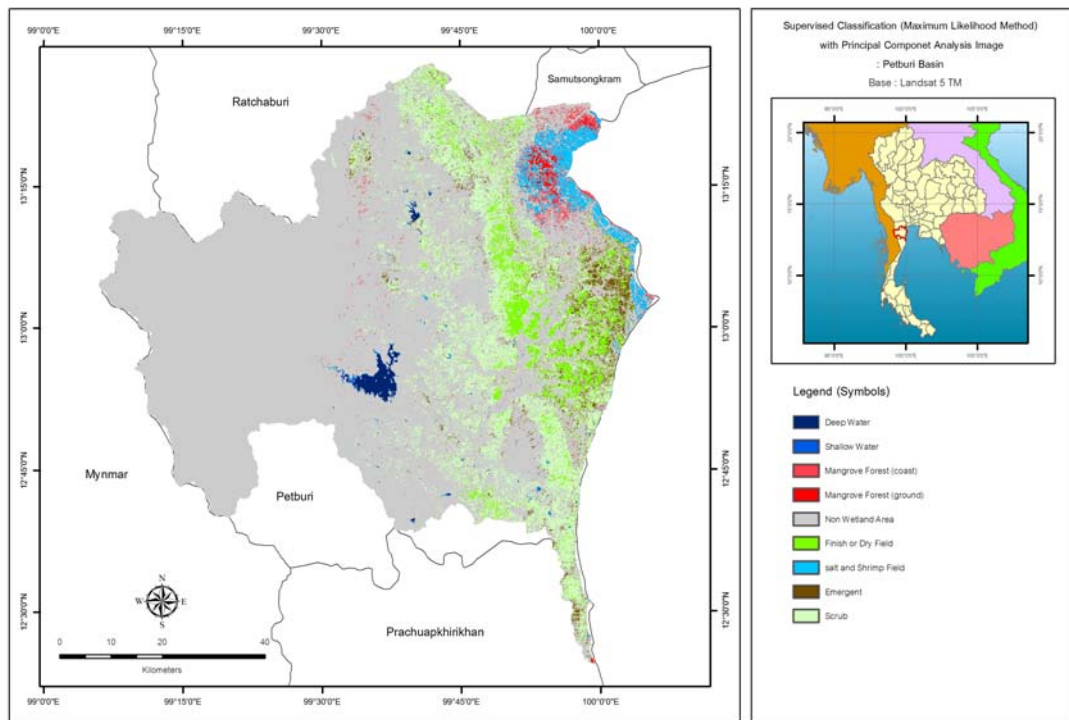


Figure 4-16: Maximum likelihood classification with Principal Component Analysis

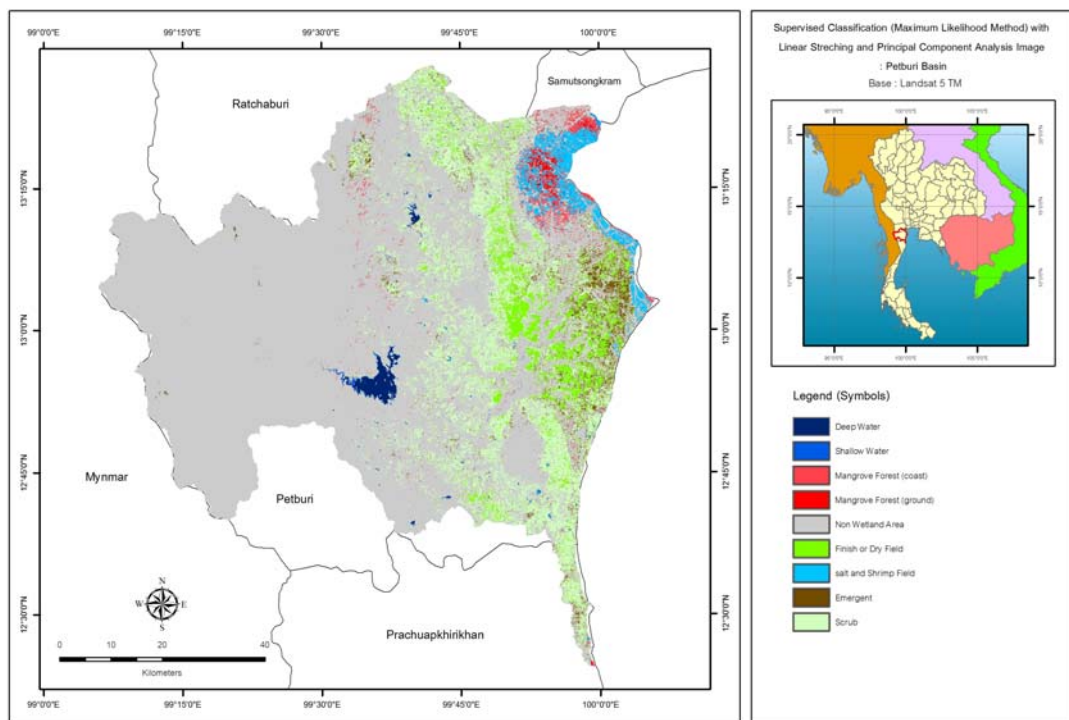


Figure 4-17: Maximum likelihood classification with linear stretching and PCA

4.3 Wetland reflection characteristics on Landsat 5 TM

Reflection characteristics are spectral signature and statistic data of reflectance with image feature from false color image of Landsat 5 TM band 453 (RGB) for each wetland class showed as below.

4.3.1 Reflection characteristics of open-water wetland

Open-water wetland has 2 classes from classification are Class 1 Deep water, showed as dark blue color area in false color image and Class 2 Shallow water showed as light blue color area in false color image. These two classes have minimum, maximum, mean and standard division as Table 4.3 and Table 4.4.

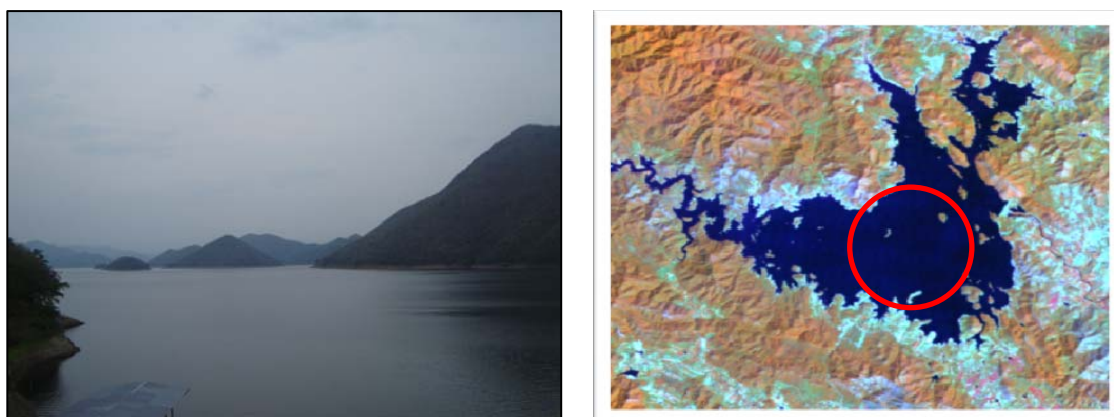


Figure 4-18: Image feature from false color image of open-water Wetland: Deep water

Table 4-3 Statistic data of Open-water Wetland: Deep water

Band	Minimum	Maximum	Mean	Standard Division
TM 1	79	89	84.35	1.75
TM 2	30	35	32.06	0.93
TM 3	26	30	27.56	0.70
TM 4	15	22	17.95	1.21
TM 5	6	15	10.50	1.41
TM 7	2	9	5.16	0.82

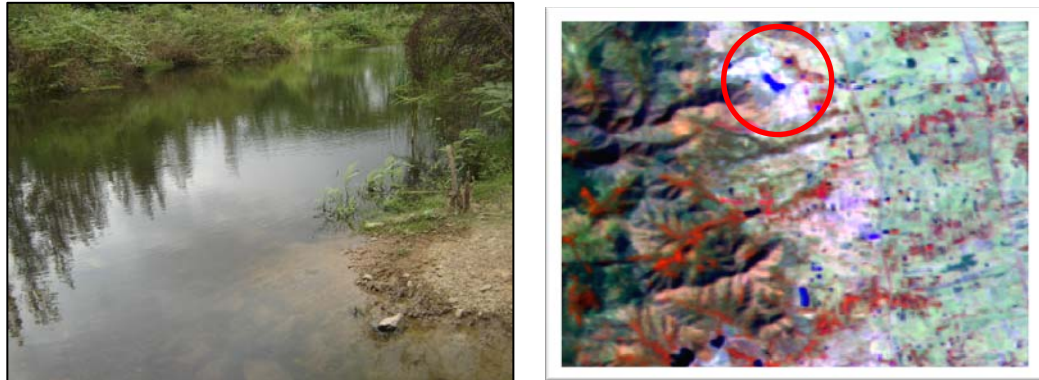


Figure 4-19: Image feature from false color image of open-water Wetland: Shallow water

Table 4-4 Statistic data of open-water Wetland: Shallow water

Band	Minimum	Maximum	Mean	Standard Division
TM 1	89	99	92.17	1.92
TM 2	39	45	41.55	1.66
TM 3	37	50	40.83	4.08
TM 4	25	33	28.22	1.65
TM 5	13	36	20.26	4.11
TM 7	6	17	9.91	2.23

Spectral signature showed high reflection on visible bands; band 1-3 then reflection is lower in infrared bands; band 4-7. Perceiving by spectral scattering that these materials absorbed in infrared bands thus graph was inclined decrease. Because of shallow water has sediment mix up with water effect to increase higher reflectance in infrared bands more than deep water. Spectral signature of open-water wetland showed as Figure 4-20.

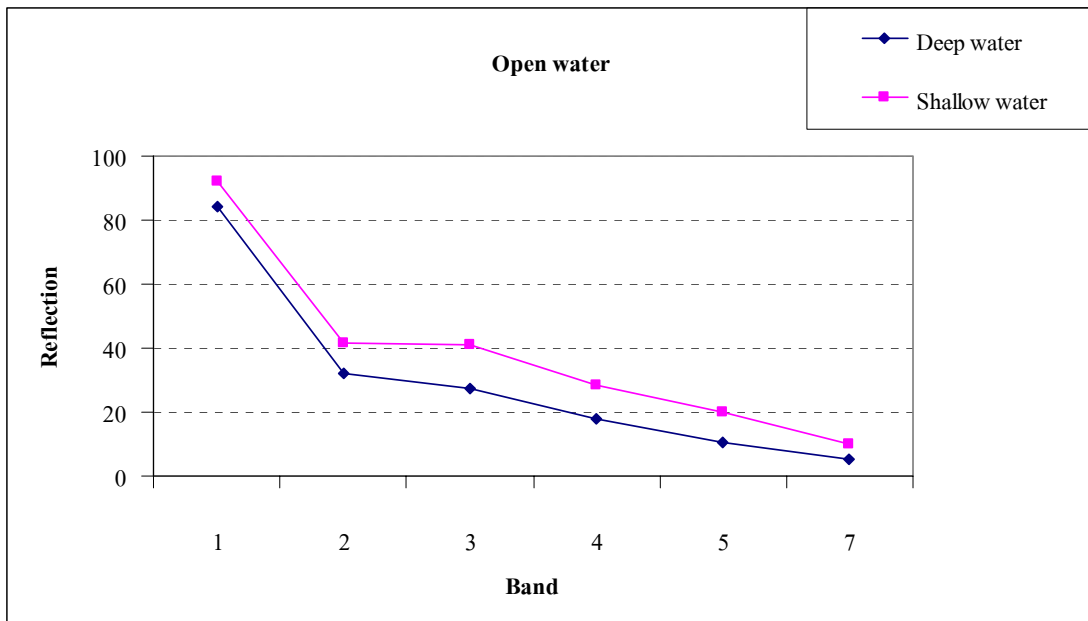


Figure 4-20 Spectral signature of open-water wetland

4.3.2 Reflection characteristics of emerged wetland

Emerged wetland has only 1 class, class 3 from classification showed as green blend with blue and gray color area in false color image. This class has minimum, maximum, mean and standard division as Table 4.5.

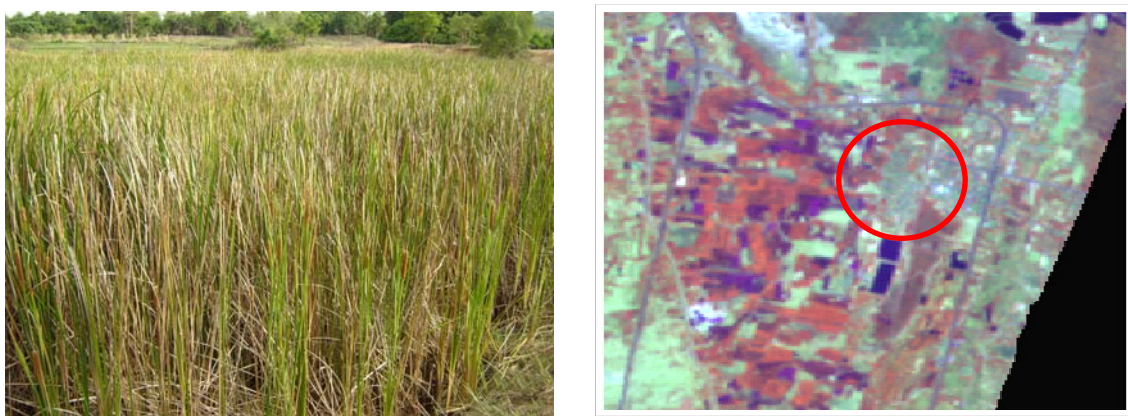


Figure 4-21: Image feature from false color image of emerged wetland

Table 4-5 Statistic data of emerged wetland

Band	Minimum	Maximum	Mean	Standard Division
TM 1	94	105	98.41	2.71
TM 2	40	48	44.05	1.87
TM 3	44	56	49.96	3.20
TM 4	57	63	59.99	1.56
TM 5	100	120	108.95	4.24
TM 7	46	70	55.16	6.56

Spectral signature showed high reflectance in band 4 and rise up in band 5. Because of environment condition in dry season this area rather bare field area mixed together with vegetation and other way, 30 meters of resolution of each pixel combine both bare field area element and vegetation area element so this class similar to scrub wetland and finish or dry rice field that also combine these element but a little lower of reflectance in band 5 because of bare field area was less than. Spectral signature of emerged wetland showed as Figure 4-22.

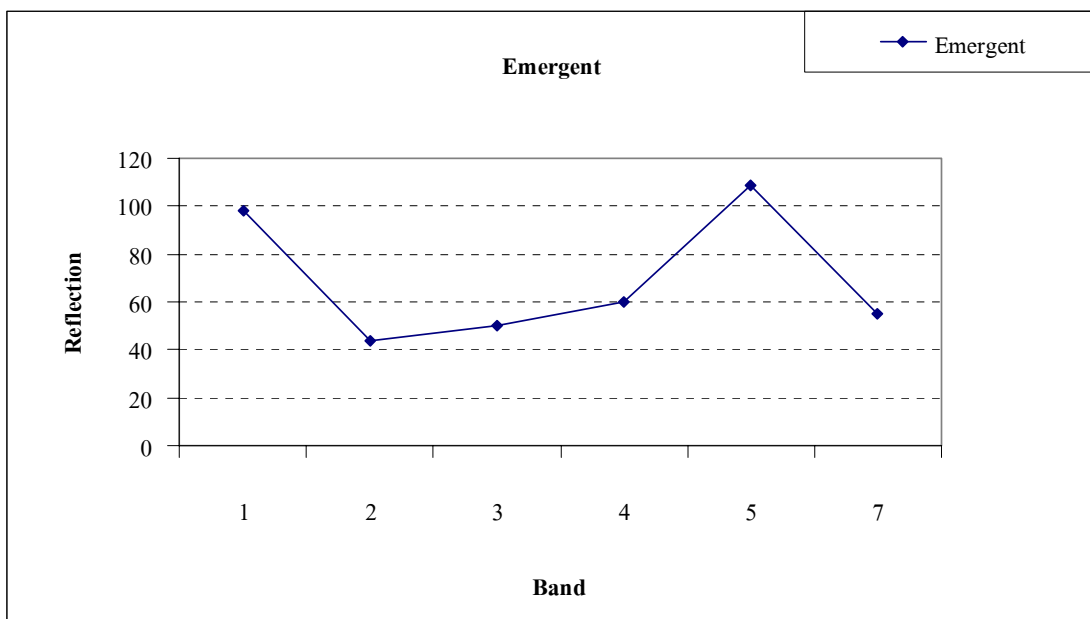


Figure 4-22: Spectral signature of emerged wetland

4.3.3 Reflection characteristics of scrub wetland

Scrub wetland has only 1 class, class 4 from classification showed as light green color rather bright green color much similar between emerged wetland and finish or dry rice field. This class has minimum, maximum, mean and standard division as Table 4.6.



Figure 4-23: Image feature from false color image of scrub wetland

Table 4-6: Statistic data of scrub wetland

Band	Minimum	Maximum	Mean	Standard Division
TM 1	92	106	99.02	3.48
TM 2	41	52	45.49	2.10
TM 3	46	62	53.71	3.43
TM 4	60	75	67.94	3.52
TM 5	97	156	132.59	11.59
TM 7	46	87	70.14	8.24

Spectral signature showed reflection similar to emerged that showed high reflectance in band 4 and rise up in band 5. But scrub wetland has little higher reflectance in band 5 because of bare field area in scrub wetland was more. Also in band 4, scrub wetland has higher reflectance because of more element of chlorophyll or vegetation element. Spectral signature of scrub wetland showed as Figure 4.24.

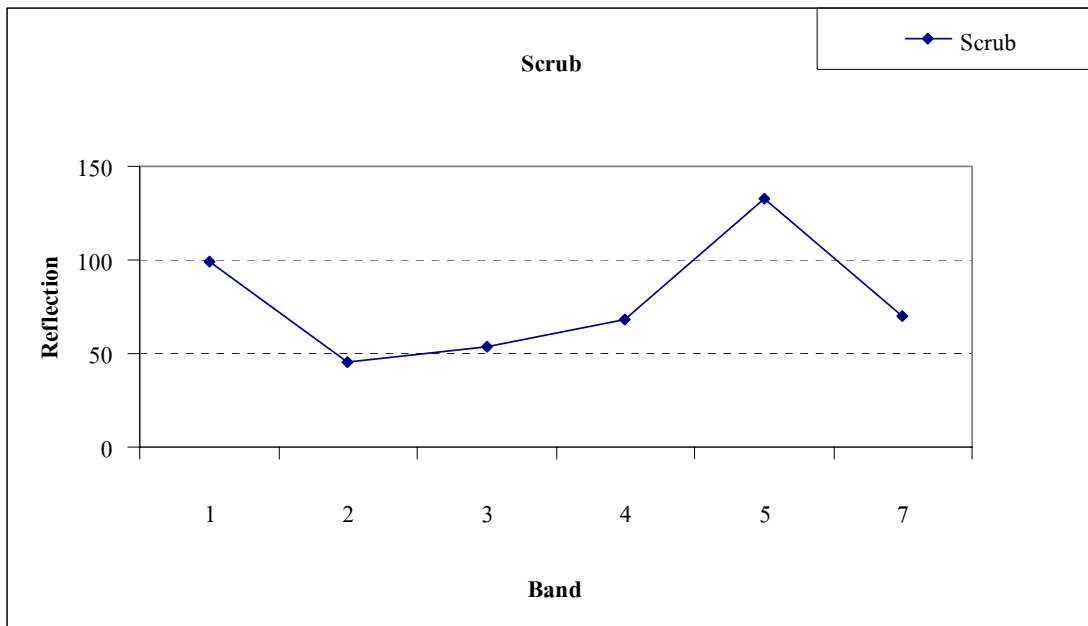


Figure 4-24: Spectral signature of scrub wetland

4.3.4 Reflection characteristics of farmland wetland

Farmland wetland has 2 classes from classification are Class 5 finish or dry rice field, showed as white blend right gray color area in false color image and Class 6 salt and shrimp field showed as light blue blend purple color area in false color image. These two classes have minimum, maximum, mean and standard division as Table 4.7 and Table 4.8.

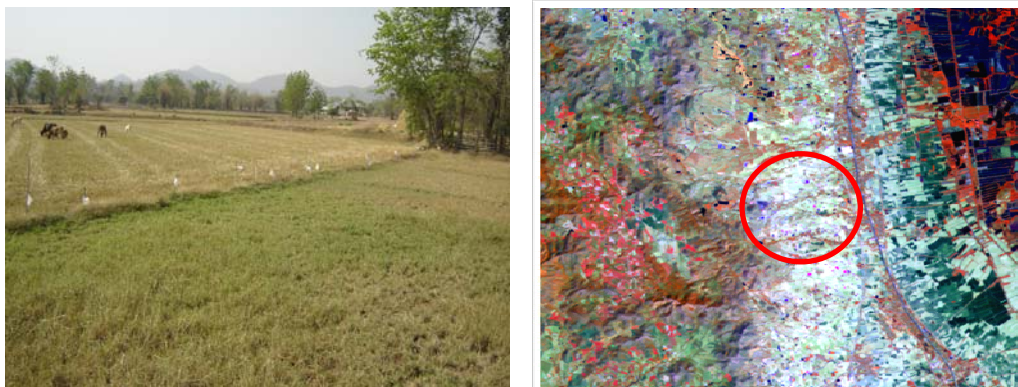


Figure 4-25: Image feature from false color image of Farmland Wetland: Finish or dry rice field

Table 4-7 Statistic data of farmland wetland: finish or dry rice field

Band	Minimum	Maximum	Mean	Standard Division
TM 1	97	108	102.47	2.09
TM 2	45	53	48.73	1.48
TM 3	56	68	62.66	2.10
TM 4	57	80	72.24	3.38
TM 5	123	173	153.97	8.61
TM 7	68	97	81.93	6.39

**Figure 4-26:** Image feature from false color image of farmland wetland: Salt and shrimp field**Table 4-8** Statistic data of farmland wetland: salt and shrimp field

Band	Minimum	Maximum	Mean	Standard Division
TM 1	86	95	90.26	2.13
TM 2	36	42	39.11	1.15
TM 3	34	41	37.95	1.82
TM 4	20	33	26.12	2.21
TM 5	10	29	16.50	4.04
TM 7	4	15	8.29	2.22

Spectral signature on this wetland type showed much difference of reflection especially in band 4 and band 5 because of environment and physical element on vegetation and soil are difference with these 2 classes. The high rising up on band 5 of finish or dry rice field mean the high bare area with soil element reflectance after finished rice field season. The pretty highs on band 4 of finish or dry rice field mean some decline vegetation in study area. For salt and shrimp field has similar reflection with shallow water because of water flood made by human to prepare pond or field for salt and shrimp, also this area was less vegetation so reflectance in infrared bands, band 4-7 are low. Anyway image that showed square shape and pattern of salt and shrimp field was help to separate this area on training area selection. Spectral signature of farmland wetland showed as Figure 4-27.

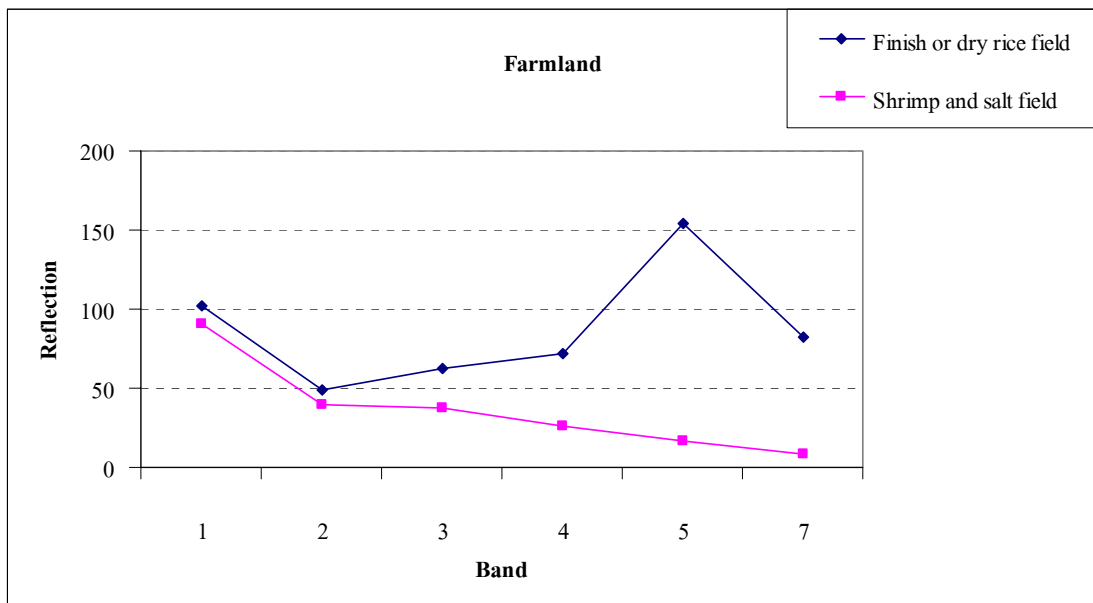


Figure 4-27: Spectral signature of farmland wetland

4.3.5 Reflection characteristics of forest wetland

Forest wetland has 2 classes from classification are Class 7 Mangrove on coast, showed as right red color area in false color image and Class 8 Mangrove on ground, showed as intensive red blend orange color area in false color image. These two classes have minimum, maximum, mean and standard division as Table 4.9 and Table 4.10.

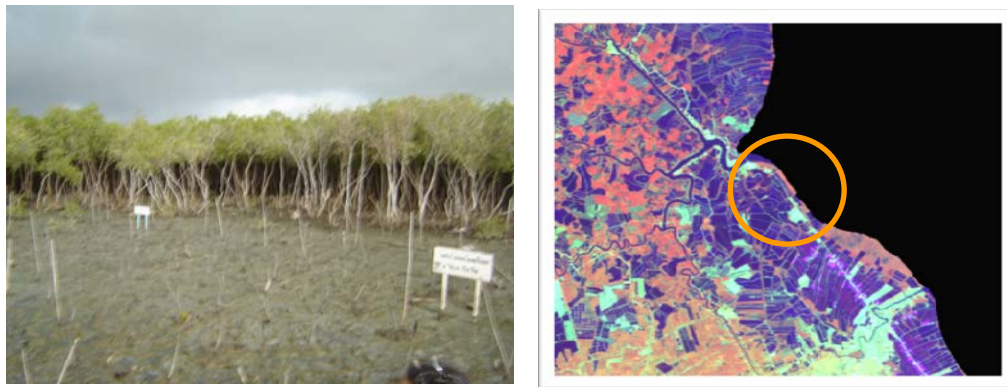


Figure 4-28: Image feature from false color image of forest wetland: mangrove on coast

Table 4-9 Statistic data of forest wetland: mangrove on coast

Band	Minimum	Maximum	Mean	Standard Division
TM 1	83	90	86.95	1.22
TM 2	35	38	36.34	0.59
TM 3	30	34	31.88	0.72
TM 4	56	77	66.92	5.60
TM 5	35	45	40.03	2.10
TM 7	10	15	12.37	1.02

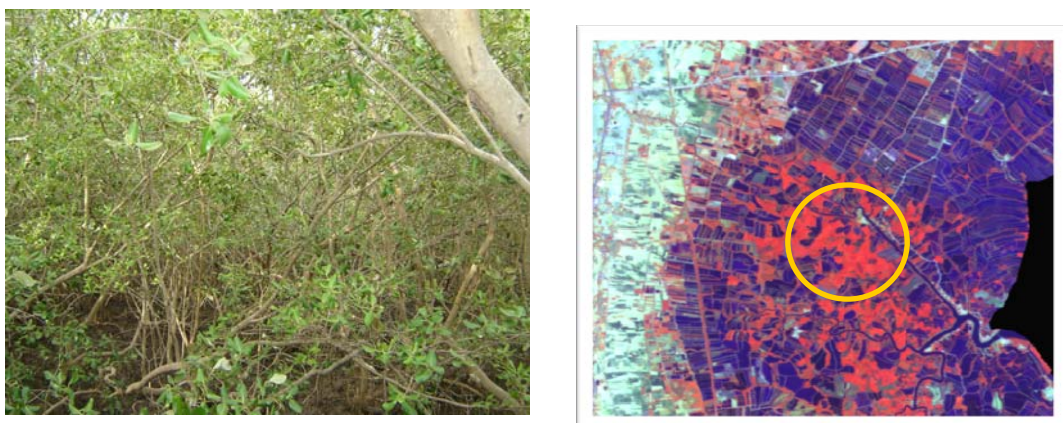


Figure 4-29: Image feature from false color image of forest wetland: mangrove on ground

Table 4-10 Statistic data of forest wetland: mangrove on ground

Band	Minimum	Maximum	Mean	Standard Division
TM 1	81	86	83.23	1.11
TM 2	32	35	33.46	0.71
TM 3	27	30	28.82	0.74
TM 4	65	84	74.97	4.20
TM 5	28	35	31.19	1.41
TM 7	6	11	9.32	0.87

Spectral signature showed a little difference reflection in band 4 between mangrove on coast and mangrove on ground because density and element of vegetation. Mangrove on ground has higher reflectance in band 4 means on ground has more mangroves. In band 5, mangrove on coast showed higher reflectance than mangrove on ground because of clay, mineral and sand that high effective reflection in this band. For overall reflection on both classes of forest wetland showed high reflection on visible bands, band 1-3 because moisture and water that continually cover this area. And chlorophyll or vegetation was the cause of graph rising up on band 4. Spectral signature of farmland wetland showed as Figure 4-30.

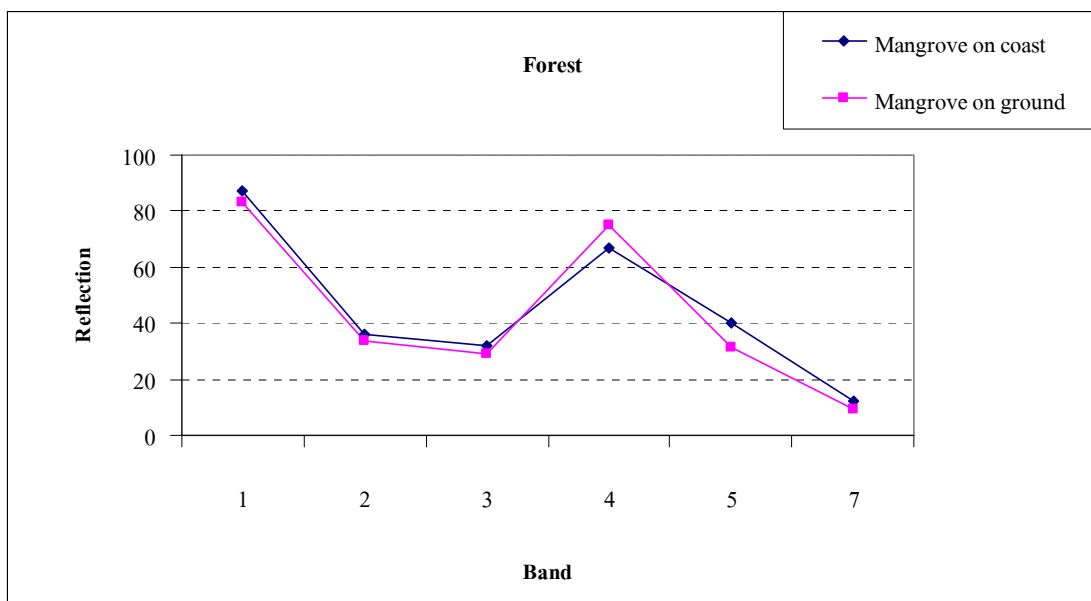


Figure 4-30: Spectral signature of Forest Wetland

4.4 Accuracy assessment

Accuracy assessment of Landsat 5 Thematic Mapper (TM) supervised classification by maximum likelihood method with varies image enhancement and transformation techniques were considered by Kappa coefficient, overall accuracy, and percentage of commission pixel and omission pixel from the cross tabulation table.

4.4.1 Kappa coefficient and overall accuracy

Kappa coefficient and overall accuracy of post supervised classification by maximum likelihood method with each enhancement and transformation technique show as Table 4-11.

Table 4-11 Kappa coefficient and overall accuracy

No.	Technique	Kappa Coefficient	Overall Accuracy
1	None (original)	0.9303	94.1079
2	Linear stretching	0.9303	94.1079
3	Principal component analysis-PCA	0.987	98.9166
4	Linear stretching and PCA	0.9854	98.784

From Kappa coefficient and overall accuracy table, accuracy assessment of original image with out enhancement and transformation techniques classified by maximum likelihood method showed K 0.9303 accuracy assessment 94.1079 % equal to classification of linear stretching image. This because of linear stretching used just basic equations ratio to compare all actual reflectance of each pixel in image to new value by capacity of computer. Computer 8 bite microprocessors has stretching level from 0 to 255 or 256 levels so this enhancement techniques was stretched all reflectance to 256 levels. All of image pixels stretched by this method so overall

component of image reflectance not much affected thus accuracy assessment by overall accuracy and Kappa coefficient are same original image.

For principal component analysis-PCA image with maximum likelihood classification method showed highest accuracy assessment $K = 0.987$ accuracy assessment 98.9166%. This because of calculation by algebra combined mechanics equation to decrease great number of image data by all principle components still remain. Result of this analysis provided new components or new bands from linear regression of many of old bands, result new bands have almost major elements of old bands but its less data number than old bands. This technique decreases much time and data size with highest accuracy assessment from components or bands after regression.

For linear stretching and PCA image with maximum likelihood classification method showed higher accuracy assessment $K = 0.9854$ accuracy assessment 98.784%. The accuracy assessment is higher than original image and linear image but lower than principal component analysis-PCA image because equation and complicated calculation. The PCA calculation is more complicated calculation than linear stretching so the combination of linear stretching and PCA was decrease efficiency of PCA. In the other way linear stretching used basic ratio calculation with image reflectance of all pixel caused reflectance image stretched and affected remaining of some band components. Finally, PCA image with maximum likelihood classification provided the highest efficiency accuracy assessment on wetland detection and classification on this study.

4.4.2 Percentage of commission pixel and omission pixel

Percentage of commission pixel and omission pixel post supervised classification by maximum likelihood method with each enhancement and transformation technique show as Table 4-12.

Table 4-12 Percentage of commission pixel and omission pixel

Classification class	Percentage of Commission pixel and Omission pixel							
	Original		Linear		PCA		Linear-PCA	
	Com	Om	Com	Om	Com	Om	Com	Om
1 Deep water	0	0	0	0	0	0	0	0
2 Shallow water	16.07	13.76	11.45	9.14	1.8	0	1.8	0
3 Emerged	7.06	1.25	7.06	1.25	1.23	0	2.44	0
4 Scrub	13.56	17.07	13.56	17.07	17.19	13.82	22.9	17.89
5 Finish or dry rice field	0.68	0.68	0.68	0.68	1.13	1.13	0.92	2.72
6 Shrimp and salt field	4.7	5.59	4.7	5.59	0	0.62	0	0.62
7 Mangrove on coast	0	0	0	0	0	0	0	0
8 Mangrove on ground	0	0	0	0	0	0	0	0

From the percentage of commission pixel and omission pixel table showed differences percentage of confused pixels on 8 classes of 5 types's wetlands on each enhancement and transformation technique with maximum likelihood classification method. Omission percentage means percentage of error pixels which were classified as other classes compare with pixels of this class based on actual condition]. And commission error percentage means percentage of error pixels which were other classes but classified as this class compare with all pixels of the class based on actual condition.

For original image with out enhancement and transformation techniques classified by maximum likelihood classification method showed confused percentage of pixels in 6 classes are shallow water, emerged, scrub, finish or dry rice field Shrimp and salt field in order. While deep water, mangrove on coast and mangrove on ground were not found any confused percentage. Result on this classification method same as linear stretching image that shallow water has highest percentage of commission 16.07% then Scrub 13.56%, Emerged 7.06%, shrimp and salt field 4.7% and finish or dry rice field 0.68%. And scrub showed highest percentage of omission 17.07% then shallow water 13.76%, shrimp and salt field 5.59%, emerged 1.25% and finish or dry rice field 0.68%.

For principal component analysis-PCA image Maximum likelihood classification method showed confused percentage of pixels in 5 classes. Scrub and finish or dry rice field are both have commission and omission. While shallow water and Emerged showed just commission error and shrimp and salt field showed just omission error. Scrub has highest percentage of commission 17.19% then shallow water 1.8%, emerged 1.23% and finish or dry rice field 1.13%. Also scrub showed highest percentage of omission 13.82% then finish or dry rice field 1.13% and Shrimp and salt field 0.62%.

For linear stretching and PCA image with maximum likelihood classification method showed confused percentage of pixels in 5 classes, scrub and finish found both commission and omission error, shallow water and Emerged found just commission error while shrimp and salt field found just omission error. Scrub still showed highest confused percentage, 22.9% for the commission and 17.89% for the omission. Emerged has 2.44% commission error then finish or dry rice field 0.92% for commission error and 2.72% for omission.

Detail of wetland types, classification classes and number of confused pixels that error on each classification method showed as cross tabulation on appendix B.

4.5 Discussion

As show in the study about wetland type and futures, wetland reflectance and accuracy assessment of wetland detection or classification with each enhancement and transformation technique, the following discussion are made with other study comparison to illustrate this study result.

4.5.1 Wetland type and basic fundamental characteristics

The wetland type in Petchaburi basin area can be classified into 5 categories: 1) Open-water Wetland 2) Emerged Wetland 3) Scrub Wetland 4) Farmland Wetland and 5) Forest Wetland, which is similar to the wetland classification system on Ramsar Convention by Simba Chan and team (2005) including 1) Marine and Coastal Wetland 2) Inland Wetland and 3) Human-Made Wetland. The first two types

consist of two sub-types like the wetland classification of Cowardin et al. (1979) while 3 types of 5 wetland types include Emerged Wetland, Scrub Wetland and Forest Wetland. Since there is no inundation in the forest area within the wetland of Petchaburi basin area for a long time, the forest wetland does not appear clearly as the coastal wetland with mangrove forest wetland, which can continually sustain the ecosystem. The third wetland type of Human-made Wetland in the study area of Petchaburi basin contains rice farm, shrimp farm and salt farm while the other 2 types of 5 wetland types based on the wetland classification of Cowardin et al. (1979) are Aquatic bed wetland and Unconsolidated bottom / shore that found very little and included as part of the Open water wetland.

Through the study of some basic characteristics such as plants, earth and hydrology on wetland in Petchaburi basin, it is found that the characteristics of wet ecosystems is consistent with the definition of Nature Serve (2008) including 1) inundation or soil saturation 2) growth adaptation of Hydrophytes which sometimes lack of oxygen as a result of water saturation and 3) long sufficient soil saturation during the growth period of plants to develop of oxygen loss around the core root zone.

In addition, it is found that the wetlands in Petchaburi basin wetland is also similar to the definition of many institutions such as Washington University (2008), Colorado State University, Environment Waikato (2007), State of Florida (2006) etc. as illustrated in the physical appeared characteristics as inundation area, sludge area, river, river estuary, mire, swamp, pond etc.

4.5.2 Wetland reflection characteristics

As studied, the reflectance values following to the interaction criteria of electromagnetic energy is different from the land cover of Ravi P. Gupta (1991) as noted. 1) Heterogeneous materials have different interaction of electromagnetic energy. This depends on the physical structural properties of each material. 2) Homogeneous materials have different interaction of heterogeneous electromagnetic energy. For example, some wave bands have high reflection while the other wave bands have high absorption or low reflection. 3) The interaction characteristic of homogeneous materials and electromagnetic energy under different time and different

environmental conditions will have different characteristics such as Mangrove Forest Wetland with changes in water flow level. Humidity levels which are differentiated by time will change the reflectance value of this area if time and humidity change. 4) The interaction characteristics of homogeneous materials and various band/channel of electromagnetic energy can be shown as the unique graph called “Spectral Signature” which can be interpreted the material classification. Based on these features, the earth surface cover can be categorized into 3 major groups as Water, Vegetation and Soil Minerals.

The wetland reflectance of Petchaburi basin provides the spectral signature result containing univariate training statistics of each wetland type in consistent with the study of land utilization using satellite data on Landsat 5 TM (Thematic Mapper) of 6 bands (bands 1-5 and band 7) of Jensen(1986). This is pointed that wetlands and water resources have reflectance characteristics in water group according to their ever lower values (due to absorption of energy).

The reflectance in Infrared group except the band 5 wetland is slightly higher because of the reflection of surface contamination. The contamination variability reflects the value of the findings in the various waves of each wetland type, which is based on the physical component of each wetland type such as plants, soil and water.

4.5.3 Wetland detection or classification with enhancement and transformation techniques

The Supervise classification is the study of Lillesand & Kiefer (1987). In case, learners have to determine the characteristics of data classes by themselves in terms of selecting sample data class to the software. The software will be processed and classified each pixel of the satellite images into classes as user required in the training area. The accuracy and reliability of classification are based on characteristics of the training area whether it covers the data class on the satellite images and whether it is the representative of all data population. Thus knowledge of learners regarding activities, environment and area conditions during the satellite processing has been extremely important. This study has classified all data into 24 classes to cover most data classes. Then, after classification, the data classes are collected as 8 wetland

classes. Those of 5 wetland classes are Open Water Wetland 2 classes, Emerged Wetland 1 class, Scrub Wetland 1 class, Farm Wetland 1 class and Forest wetland 1 class. The others will be categorized into additional 1 class.

Using maximum likelihood methods with data Landsat 5 TM 6 bands of this study can provide the overall accuracy result at 94.11% regardless the combination of image enhancement and transformation techniques, which is higher than the study of shrub and grassland ecosystem of Hewitt (1990) using the same data, only 3 bands 2, 4 and 7 with Algorithm of maximum likelihood classification and 16 classes of classification in the final existing map likely having 81% accuracy. The study is based on GIS application model to identify the forest wetlands in Maine State of Sader et al (1995), clustering the unsupervised statistical segmentation principles for training area of maximum likelihood classification, compared with the Rule-based GIS classification and band data 3,4 and 5, which both methods can provide only 80% accuracy. The study of Lunetta and Barlogh (1999) used the Simple rule-base to classify types of wetlands and plants in the upland of Maryland and Delaware State by 2 time images of band 5 which having quality adjustment with Gray-level thresholding techniques to enter the classification resulting to 88% overall maximum accuracy. In addition, the Hyperspectral imagery on wetlands are made to consider the scope of wetlands of plant communities by M.Y. Jollineau and P.J. Howarth (2007) using 2 types of algorithm classification such as maximum likelihood (MLC) and spectral angle mapper (SAM) including compact airborne spectrographic image (CASI). Using of MCL can provide 10 classes of plant community areas with 92% accuracy. So, upon the comparison of classification results on wetlands and other education found that the basic image enhancement and transformation techniques are available and ready-to-use software techniques, which can provide the overall accuracy of high classification if using supervised classification based on sufficient detailed field data or area data to determine the wetland data types and other area data of educator in order to represent the range of all types of satellite image data.

Based on the Image enhancement and transformation techniques of this study, the linear stretching of Image Stretching techniques are indifferent from the maximum likelihood techniques and provide the classified accuracy of 94.11%. Due to the linear stretching is the comparative ratio of the existing reflectance ranking from 0

to 255 or 256 levels (as the capability of an 8-bit computer). All expanded reflectance make the differences of the overall material reflectance of the virtual image be unchanged from the original. Thus, the results of the classification are valuable as the classification from the Original image. Through using Principal Component Analysis-PCA together with maximum likelihood method that provides the highest accuracy is due to PCA to bring a number of image data to calculate both algebra and mechanics mutually, and then reduce the number of data. However, almost all prominent features of most data remain. The analysis will provide new component or new band arising from linear combination; therefore, the highest accuracy is 98.92%. In case of using the linear stretching and PCA techniques together with methods maximum likelihood, the accuracy is higher than using only linear stretching technique with maximum likelihood method, which is accurate to 98.78% due to the greater complexity of the equations to calculate new component or new band of the PCA in order to support the linear stretching techniques to enhance more accurate results of detection. In contrast, the complexity of PCA equation is greater than the linear stretching technique resulting to slightly ease the efficiency of PCA equation through the integration of linear stretching techniques and PCA together with the maximum likelihood method. Consequently, the overall accurate result is less than using only PCA technique and maximum likelihood method. It is apparent that PCA technique effectively applied to detect and identify the wetlands.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study used remote sensing data from Landsat 5 TM taken in January, 2007 with maximum likelihood method on supervise classification with vary basic enhancement and transformation techniques to compare overall accuracy assessment and image processing result for high efficiency appropriate method to detect and classify wetland in synthesis. Image processing and accuracy assessment in Phetchaburi basin are concluded as follow.

Satellite image, Landsat 5 TM path 129 row 051 and path 130 row 051 was used to represent the area studied. The study was started by image processing that the 2 sheets satellite image was merged and subsetting to focus on Phetchaburi basin. Then the image was registered a real world coordinate by the geometric correction. Next, it was performed by image enhancement and transformation techniques for better display and data preparing before classification process. Enhancement and transformation techniques used with Landsat 5 TM image on this process as follow: 1. False Color Composite Image RGB 453 2. Image operation, vegetation index (Normalized Difference Vegetation Index-NDVI) 3. Image Stretching, linear stretching and 4. Principal Component Analysis-PCA. After that the False Color Composite Image RGB 453 result was used for training area selection for supervised classification method. Other result and original satellite image were input to supervise classification with maximum likelihood to twenty-four subcategories by mean of field observation spectral analysis. Then concluded twenty-four subcategories to be 6 categories i.e. open water wetland, emerged wetland, scrub wetland, farm wetland, forest wetland and the other.

Image operation and post classification of each technique to detect wetland were compared for unstableness and accuracy assessment by Kappa Index Agreement (K), Overall accuracy and confusion matrix with commission error and omission error.

The results from image operation and accuracy assessment of each technique found that image operation technique, vegetation index (NDVI) made image

more clear with all component and enhance vegetation to be outstanding and. Due to the result of each pixel reflectance is between -1 to 1 after image operation thus this technique can not input to classification but it can supporting image operation on training area selection same as False Color Composite Image technique especially with supervise classification. For Image Stretching, linear stretching and PCA techniques were validity to apply in image classification for wetland detection. Comparing of overall accuracy for wetland classification found that Supervise Classification and Maximum Likelihood Classification with PCA technique has the highest accuracy: 98.92%. The second overall accuracy is 98.78% from the combination of 2 techniques: image stretching technique and PCA technique. For Classification that used only Image stretching technique; the overall accuracy is 94.11% that is equal to using Supervise Classification and Maximum Likelihood Classification without technique.

5.2 Recommendations

There are two recommendations: recommendation for remote sensing or satellites data application on wetland detection and recommendation for further study.

5.2.1 For further study

5.2.1.1 Applied Satellite Data

1) Update satellite data applied to the study is recommended in order to categorize the maximizing output of actual site survey.

2) In case of multiple map sheets of satellite data, each data with most adjoining recording time is recommended to prevent absolute spectral reflectance(R) values and spectral components. Unavoidably, qualitative adjustment of spectral reflectance values is required prior to integrated data applying.

3) To study wetland with remote sensing technique not emphasizing on investigation of spectral reflectance values, the process is unnecessary for applying raw satellite images from all spectral bands for image classification. The

application of this procedure should exclude unconcerned area for the purpose that number of pixels and onboard image processing time is relatively reduced.

5.2.1.2 Site Survey Spots Determination

1) The launch mass should be determined to collect land cover and land use information of the study area covering principle land use patterns of the watershed. The framework includes not only the wetland but also crowded area, urban area, road, business area, farmland, orchard area and others. The step would efficiently assist classification accuracy of satellite data.

2) Site survey is the investigation of actual study area with record of retracting time series. Thereby, additional inquiry of local people during field data collection is primarily concerned more.

5.2.1.3 Field Data Collection Planning

1) Three phases of field data collection should be planned: 1) Survey and study of overview area is to emphasize on investigation of land cover and land use prior to launch mass in the study area 2) Data collection subject to launch mass for imagery interpretation or training area determination 3) And field operation after satellite data classification to determine sampling area for inspection of data classification with absolute accuracy.

2) Site data collection should be performed in the same or almost time-periodic variation of satellite to acquire real time data sets under actual conditions of the study area that would mostly facilitate understanding of data classification.

5.2.1.4 Applied image enhancement and transformation techniques

1) Before applying image enhancement and transformation techniques on satellite data to detected or classify satellite data should include the study result after its enhancement and transformation. Because resulting output from some techniques cannot be employed to equation for classification such as image operation which spectral reflectance value of each pixel are employed to the equation. The result is spectral reflectance of each pixel between -1 to 1 that is not the actual value of reflectance. So the classification cannot be further operated.

2) The study is merely primary applied techniques of enhancement and transformation for satellite data of processing program. In this regard, more complex techniques are given under the data processing program that whoever interesting could further investigate in applying of satellite data in studying wetland.

5.2.1.5 Data Base Management

1) Data derived from the wetland and watershed area should be systematically stored in data base information in form of spatial data, attribute data. The stakes should mutually determine the standard with the same data pattern to increase rapidness in integrating applied data application for enhancing and encouraging management of wetland conservation.

5.2.2 For application

Preliminary enhancement and transformation techniques of satellite data in the study should be applied for the other wetland areas or applied for vary wetland type. Its resulting accuracy is comparable to develop preliminary techniques to practical application. The operation should include complex techniques for enhancement and transformation of scanning and classifying wetland. For instance, mathematical model or spatial calculation model etc. The research is recommended to include comparative study for remote sensing (RS) from various satellites. Such as studying satellite data from SPOT comparable to Landsat to decrease utilization of primary data and data site collection. Contrarily, the operation is emphasized on remote sensing (RS) application in associate with Geography Information System(GIS) as well as secondary data e.g. topographic map, watershed data. The procedure is aimed at reducing time period and budget for field operation, supporting wetland conservation with upmost performance, overtaking a variety of actual situations. The study on several impacts causing from land cover and land use changes from wetland conservation is accordingly crucial and necessary components for wetland conservation and management in a sustainable way at present.

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APPENDICES

APPENDIX A

แบบสำรวจข้อมูลภาคสนามพื้นที่ชุ่มน้ำ

วันที่บันทึก _____ เวลา _____ พอร์ทเลขที่/จุดศึกษาที่ _____
 ผู้บันทึก _____ สถานที่ _____
 พิกัดตำแหน่ง N _____ E _____
 ความสูงจากระดับน้ำทะเลปานกลาง _____ ความชัน _____
 ระวังแผนที่ _____ ตำบล _____ อำเภอ _____ จังหวัด _____

1. พืชพรรณ : Hydrophytic Vegetation

ลำดับ	ชื่อ/ชนิดพืช	%ในพื้นที่	หมายเหตุ	ลำดับ	ชื่อ/ชนิดพืช	%ในพื้นที่	หมายเหตุ
1				9			
2				10			
3				11			
4				12			
5				13			
6				14			
7				15			
8				16			

%ของพืชในพื้นที่ชุ่มน้ำ OBL, FACW และ/หรือ FAC: _____ %

ดัชนีชี้วัดอื่นๆ:

-*มีพืชในพื้นที่ชุ่มน้ำท้องถิ่น (سوبถาม) ใช่ _____ ไม่ _____

-*มีการปรับตัวทางกายภาพของพืช (ฟองน้ำ, ผงผนังเซลล์มีรูพรุน.....) ใช่ _____ ไม่ _____

-*เจริญเติบโตได้ในพื้นที่ชุ่มน้ำ ใช่ _____ ไม่ _____

-*สามารถขยายพันธุ์ในพื้นที่ชุ่มน้ำ ใช่ _____ ไม่ _____

เป็น Hydrophytic Vegetation: ใช่ ไม่

2 . ดิน : Hydric Soils

- เจาะดินที่ความลึก 8-16 นิ้วพบน้ำ (ดินอิ่มตัวด้วยน้ำ)

ใช่ _____ ไม่ _____

- มีจุดประ (สีจุดประ: _____)

ใช่ _____ ไม่ _____

ค่า Hue _____

ค่า Value _____

ค่า Chroma _____

- พบดินเป็นสีเทา (สีเนื้อดินหลัก: _____)

ใช่ _____ ไม่ _____

เนื้อดิน: ดินเหนียว ดินร่วน ดินทราย ดิน.....

- มี Organic material

ใช่ _____ ไม่ _____

น้อยกว่า 20% 20% 30% 40% 50% 60% >60%

ดัชนีชี้วัดอื่นๆ:

-7.5 cm. พบเม็ดหินสีดำและน้ำตาลเข้มเส้นผ่าศูนย์กลางมากกว่า 2 mm.

ใช่ _____ ไม่ _____

(Iron and Manganese concretions)

-กลินก๊าซไข่น้ำ (ซัลเฟอร์)

ใช่ _____ ไม่ _____

-*ชื่อชุดดิน _____ อยู่ในรายการกลุ่มดินของพื้นที่ชุ่มน้ำ

ใช่ _____ ไม่ _____

เป็น Hydric Soils: ใช่ <input type="checkbox"/> ไม่ <input type="checkbox"/>
--

3. น้ำ : Hydrology

• มีน้ำท่วมขัง ใช่ ไม่

น้ำท่วมตลอดปี น้ำท่วมบางฤดูกาล น้ำขึ้นน้ำลง

ความลึกของระดับน้ำ: _____ เมตร

ระดับความเค็ม: _____ น้อยกว่า 0.5 S‰ 0.5 - 30 S‰ > 30 S‰

• ดินอิ่มตัวด้วยน้ำ: ใช่ ไม่

ความลึกของดินอิ่มตัวด้วยน้ำ: ที่ระดับความลึก 8- 16 นิ้ว พบน้ำที่ระดับ _____ นิ้ว

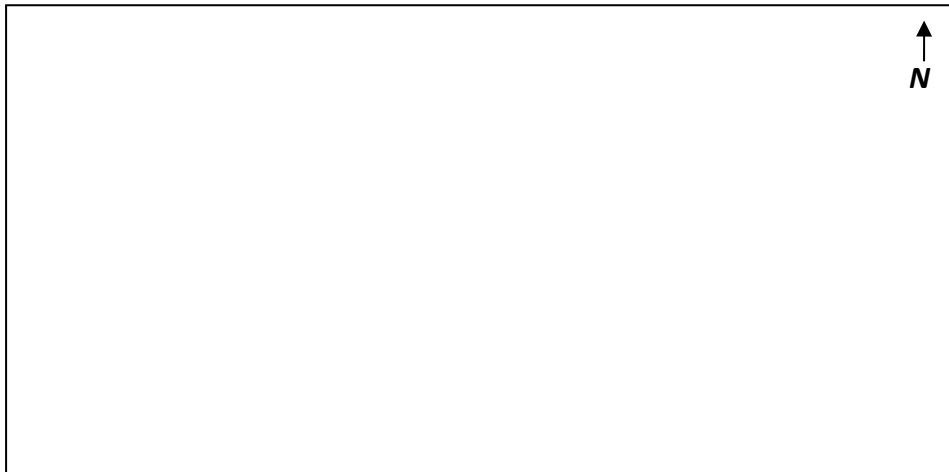
ดัชนีชี้วัดอื่นๆ:

-พบรอยระดับน้ำ (Water Mark) ใช่ ไม่

-พบแนวกองทราย (Drift line) ใช่ ไม่

-พบสิ่งตกตะกอน (Sediment deposits) ใช่ ไม่

-ลักษณะลำน้ำและการไหลของน้ำ (Drainage patterns)



ปรากฏลักษณะ Wetland hydrology: ใช่ ไม่

การกำหนดพื้นที่ชุ่มน้ำ : เป็นพื้นที่ชุ่มน้ำ ไม่เป็นพื้นที่ชุ่มน้ำ

เป็นพื้นที่ชุ่มน้ำประเภท

1) แหล่งน้ำ 2) พืชน้ำ 3) ไม้พุ่ม

4) ป่าในพื้นที่ชุ่มน้ำ 5) ฟาร์มในพื้นที่ชุ่มน้ำ 6) อื่นๆ

บันทึกและคำแนะนำ _____

กำหนดโดย _____

APPENDIX B

CROSS TABULATION OF EACH METHOD CLASSIFICATION

1. Cross tabulation of Maximum likelihood method classification

Class		c1	c2	c3	c4	c5	c6	c7	c8	c9	Total pixel
C0	Can not classify	0	0	0	0	0	0	0	0	0	0
C1	Deep water	2157	0	0	0	0	0	0	0	0	2157
C2	Shallow water	0	94	0	0	0	18	0	0	0	112
C3	Emergent	0	0	79	6	0	0	0	0	0	85
C4	Scrub	0	0	0	102	1	0	0	0	15	118
C5	Finish or dry rice field	0	0	0	0	438	0	0	0	3	441
C6	Shrimp and salt field	0	15	0	0	0	304	0	0	0	319
C7	Mangrove on coast	0	0	0	0	0	0	113	0	0	113
C8	Mangrove on ground	0	0	0	0	0	0	0	116	0	116
C9	Other	0	0	1	15	2	0	0	0	5567	5585
Total pixel		2157	109	80	123	441	322	113	116	5585	9046

2. Cross tabulation of Linear stretching with Maximum likelihood method classification

Class		c1	c2	c3	c4	c5	c6	c7	c8	c9	Total pixel
C0	Can not classify	0	0	0	0	0	0	0	0	0	0
C1	Deep water	2157	0	0	0	0	0	0	0	0	2157
C2	Shallow water	0	94	0	0	0	18	0	0	0	112
C3	Emergent	0	0	79	6	0	0	0	0	0	85
C4	Scrub	0	0	0	102	1	0	0	0	15	118
C5	Finish or dry rice field	0	0	0	0	438	0	0	0	3	441
C6	Shrimp and salt field	0	15	0	0	0	304	0	0	0	319
C7	Mangrove on coast	0	0	0	0	0	0	113	0	0	113
C8	Mangrove on ground	0	0	0	0	0	0	0	116	0	116
C9	Other	0	0	1	15	2	0	0	0	5567	5585
Total pixel		2157	109	80	123	441	322	113	116	5585	9046

3. Cross tabulation of Principal component analysis-PCA with Maximum likelihood method classification

Class		c1	c2	c3	c4	c5	c6	c7	c8	c9	Total pixel
C0	Can not classify	0	0	0	0	0	0	0	0	0	0
C1	Deep water	2157	0	0	0	0	0	0	0	0	2157
C2	Shallow water	0	109	0	0	0	18	0	0	0	127
C3	Emergent	0	0	79	6	0	0	0	0	0	85
C4	Scrub	0	0	0	102	1	0	0	0	15	118
C5	Finish or dry rice field	0	0	0	0	438	0	0	0	3	441
C6	Shrimp and salt field	0	0	0	0	0	304	0	0	0	304
C7	Mangrove on coast	0	0	0	0	0	0	113	0	0	113
C8	Mangrove on ground	0	0	0	0	0	0	0	116	0	116
C9	Other	0	0	1	15	2	0	0	0	5567	5585
Total pixel		2157	109	80	123	441	322	113	116	5585	9046

4. Cross tabulation of Linear stretching and PCA with Maximum likelihood method classification

Class		c1	c2	c3	c4	c5	c6	c7	c8	c9	Total pixel
C0	Can not classify	0	0	0	0	0	0	0	0	0	0
C1	Deep water	2157	0	0	0	0	0	0	0	0	2157
C2	Shallow water	0	94	0	0	0	18	0	0	0	112
C3	Emergent	0	0	79	6	0	0	0	0	0	85
C4	Scrub	0	0	0	102	1	0	0	0	15	118
C5	Finish or dry rice field	0	0	0	0	438	0	0	0	3	441
C6	Shrimp and salt field	0	15	0	0	0	304	0	0	0	319
C7	Mangrove on coast	0	0	0	0	0	0	113	0	0	113
C8	Mangrove on ground	0	0	0	0	0	0	0	116	0	116
C9	Other	0	0	1	15	2	0	0	0	5567	5585
Total pixel		2157	109	80	123	441	322	113	116	5585	9046

APPENDIX C
WETLAND CHARACTERISTIC DATA FROM FIELD SURVEYING IN PHETCHABURI BASIN

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
1	10 Feb 09	603680	1404958	4	-	8	รูดิษ,ต้นสน	Y
2	10 Feb 09	604548	1402651	1	26	7	ต้นสน,ต้นมะขามเทศน์	Y
3	10 Feb 09	617721	1440631	2	19	8	ต้นสน,มะขามเทศ	N
4	14 Feb 09	574664	1456378	71	5	7	กก,ตะไคร่น้ำ,จอก,ผักตบ,เฟริน	Y
5	14 Feb 09	578734	1437611	42	70	8	ต้นตึกแก,ไมยราบ,หญ้า,ผักบั้งใบแหลม	N
6	14 Feb 09	579674	1435369	47	100	9	-	N
7	14 Feb 09	568158	1427749	109	100	9	สาหร่ายหางกระรอก	Y
8	14 Feb 09	569499	1427430	55	89	8	บอน,หญ้า,ไมยราบ,ดอกหญ้า,ผักจรูด	N
9	15 Feb 09	587838	1443785	29	56	8	หญ้า,กก,รูดิษ,ผักตบชวา	N
10	15 Feb 09	587113	1443550	42	97	7	หญ้า,ดอกหญ้า	Y
11	15 Feb 09	587233	1443892	39	65	8	กก,รูดิษ,บัว,ผักบั้ง,กระเจตปน,ไมยราบเล็ก	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
12	15 Feb 09	615801	1438250	-5	6	7	ไมยราบ, ฝักบัวทะเล, ฝักเครือเถาสีเหลืองทอง	N
13	15 Feb 09	615258	1448211	0	-	8	-	N
14	8 Mar 09	596306	1406371	48	55	7	-	Y
15	8 Mar 09	592367	1407420	114	100	7	สาหร่ายน้ำจืด	Y
16	8 Mar 09	586526	1408962	55	10	7	หญ้า, ฝักบัว	Y
17	8 Mar 09	579209	1405148	87	67	8	หญ้า, บัว, ป่าน	Y
18	8 Mar 09	568475	1417634	69	50	8	ฝักแวน, ฝักบัว, หญ้า	Y
19	8 Mar 09	567356	1414691	103	61	8	-	Y
20	8 Mar 09	570597	1419195	81	100	7	-	Y
21	8 Mar 09	573578	1422202	62	100	8	หญ้า, บอน	N
22	8 Mar 09	569024	1427865	56	100	8	-	Y
23	16 May 09	579102	1405031	43	18	7	ต้นกกหนองไถ่	Y
24	16 May 09	576383	1460332	37	-	6	ฝักบัว, จอก	Y
25	16 May 09	573748	1456509	62	38	8	บอน/ไมยราบ	Y
26	16 May 09	573190	1459275	89	74	9	-	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
27	16 May 09	576473	1459343	99	59	7	ผักนึ่ง,ต้นกก,ตะไคร่น้ำ,ธูปฤๅษี	Y
28	16 May 09	577311	1461793	115	64	8	-	-
29	16 May 09	584920	1459878	49	55	9	ไมยราบ,หญ้าคา,ผักนึ่ง	Y
30	16 May 09	586070	1458287	40	25	8	-	Y
31	7 Jul 09	611556	1429722	0	14	4	ขุ้,ไมยราบ,กระบองเพชร	Y
32	11 Jul 09	566561	1452098	154	16	4	ไมยราบยักษ์ กบ บัว โสน สาหร่าย ผักนึ่ง ผักปราง	Y
33	11 Jul 09	567407	1451559	155	16	4	จอก แหน สาหร่าย ไมยราบ	Y
34	11 Jul 09	580889	1437008	42	18	3	ไมยราบยักษ์ ธูปฤๅษี บอน	Y
35	11 Jul 09	588264	1445705	27	18	4	หญ้า	N
36	18 Jul 09	587636	1432349	32	35	4	กก	Y
37	18 Jul 09	597319	1441301	13	20	4	บัว กระเจ็ด	Y
38	19 Jul 09	606476	1416904	5	6	4	ปรง ธูปฤๅษี ไมยราบ ไมยราบยักษ์ กก กกหนองน้ำ ใ้จู้	Y
39	19 Jul 09	599591	1442707	5	22	5	ไมยราบ ไมยราบยักษ์ อ้อ	N
40	19 Jul 09	592041	1434676	17	15	4	ธูปฤๅษี กก	N
41	10 Feb 09	604772	1411660	3	6	8	กก,เฟิร์น	-

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
42	10 Feb 09	603446	1398586	3	23	8	รูดิณี,กค	Y
43	10 Feb 09	603377	1400363	7	47	9	แวนแก้ว,พุทธรักษา,รูดิณี,บอน	-
44	10 Feb 09	603496	1405665	9	49	9	รูดิณี	-
45	10 Feb 09	604706	1411654	27	22	9	ปรง,กค	-
46	14 Feb 09	578222	1441061	42	22	8	รูดิณี,หญ้า,ไมยราบ,ดอกหญ้า,ต้นพุทธรักษาเล็ก,ผักนึ่ง	Y
47	15 Feb 09	592806	1443479	5	24	0	ผักนึ่ง,ผักตบชวา,หญ้า,ผักตำลึง,แหวน	Y
48	7 Jul 09	611556	1429722	0	14	4	หญ้า,ไมยราบ,กระบองเพชร	Y
49	11 Jul 09	566561	1452098	154	16	4	ไมยราบยักษ์ กบ บัว โสน สาหร่าย ผักนึ่ง ผักปราง	Y
50	11 Jul 09	567407	1451559	155	16	4	จอก แหน สาหร่าย ไมยราบ	Y
51	11 Jul 09	580889	1437008	42	18	3	ไมยราบยักษ์ รูดิณี บอน	Y
52	11 Jul 09	588264	1445705	27	18	4	หญ้า	N
53	18 Jul 09	587636	1432349	32	35	4	กค	Y
54	18 Jul 09	597319	1441301	13	20	4	บัว กระเจ็ด	Y
55	19 Jul 09	606476	1416904	5	6	4	ปรง รูดิณี ไมยราบ ไมยราบยักษ์ กค กคทองอนไถ่ ทุ่ง	Y
56	19 Jul 09	599591	1442707	5	22	5	ไมยราบ ไมยราบยักษ์ ่อ	N

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
57	19 Jul 09	592041	1434676	17	15	4	รูดงก	N
58	10 Feb 09	604772	1411660	3	6	8	กก,เฟริน	-
59	10 Feb 09	603446	1398586	3	23	8	รูดงก	Y
60	10 Feb 09	603377	1400363	7	47	9	แวนแก้ว,พุทธรักษา,รูดงก,บอน	-
61	10 Feb 09	603496	1405665	9	49	9	รูดงก	-
62	10 Feb 09	604706	1411654	27	22	9	ปรง,กก	-
63	14 Feb 09	578222	1441061	42	22	8	รูดงก,หญ้า,ไมยราบ,ดอกหญ้า,ต้นพุทธรักษาเล็ก,ผักนึ่ง	Y
64	15 Feb 09	592806	1443479	5	24	0	ผักนึ่ง,ผักตบชวา,หญ้า,ผักตำลึง,แหน	Y
65	7 Jul 09	611556	1429722	0	14	4	ปู,ไมยราบ,กระบองเพชร	Y
66	11 Jul 09	566561	1452098	154	16	4	ไมยราบยักษ์ ก บัว โสน สำหรับ ผักนึ่ง ผักปราง	Y
67	11 Jul 09	567407	1451559	155	16	4	จอก แหน สำหรับ ไมยราบ	Y
68	11 Jul 09	580889	1437008	42	18	3	ไมยราบยักษ์ รูดงก บอน	Y
69	11 Jul 09	588264	1445705	27	18	4	หญ้า	N
70	18 Jul 09	587636	1432349	32	35	4	กก	Y
71	18 Jul 09	597319	1441301	13	20	4	บัว กระเจ็ด	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
72	19 Jul 09	606476	1416904	5	6	4	ปรัง ฐปถยัฒ ฒมรยยัฒ กก กกหงอนไค้ ฐุ่	Y
73	19 Jul 09	599591	1442707	5	22	5	ฒมรยยัฒ ฒมรยยัฒ อ้อ	N
74	19 Jul 09	592041	1434676	17	15	4	ฐปถยัฒ กก	N
75	10 Feb 09	604772	1411660	3	6	8	กก,เฟรน	-
76	10 Feb 09	603446	1398586	3	23	8	ฐปถยัฒ,กก	Y
77	10 Feb 09	603377	1400363	7	47	9	แวนแคว้,พฐรยัฒ,ฐปถยัฒ,บอน	-
78	10 Feb 09	603496	1405665	9	49	9	ฐปถยัฒ	-
79	10 Feb 09	604706	1411654	27	22	9	ปรัง,กก	-
80	14 Feb 09	578222	1441061	42	22	8	ฐปถยัฒ,หญ้, ฒมรยยัฒ,ดอกหญ้,ต่นพฐทรยัฒ,ต่นพฐทรยัฒ,ต่นพฐทรยัฒ	Y
81	15 Feb 09	592806	1443479	5	24	0	ต่นพฐทรยัฒ,ต่นพฐทรยัฒ,หญ้,ต่นพฐทรยัฒ,ต่นพฐทรยัฒ	Y
82	7 Jul 09	593276	1452093	6	27	3	กก,ฐปถยัฒ,ปรัง	Y
83	7 Jul 09	597636	1453340	9	18	4	กก	Y
84	7 Jul 09	597637	1452188	5	22	3	กก,ฐปถยัฒ,บ้ว	Y
85	7 Jul 09	611731	1432049	0	14	3	ฐปถยัฒ	Y
86	7 Jul 09	611658	1432266	5	15	3	ฐปถยัฒ	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
87	11 Jul 09	592317	1452936	4	12	3	ธูปถัสน์	N
88	11 Jul 09	581682	1452814	88	30	5	ธูปถัสน์	-
89	11 Jul 09	577886	1449646	66	34	5	ธูปถัสน์, กก	Y
90	11 Jul 09	596257	1444907	7	18	4	บัว	Y
91	11 Jul 09	593966	1445454	7	14	5	ธูปถัสน์, กก	Y
92	11 Jul 09	590683	1449649	9	30	3	ธูปถัสน์	Y
93	11 Jul 09	591458	1450715	3	40	6	ธูปถัสน์	N
94	18 Jul 09	579030	1436898	52	33	4	ธูปถัสน์	Y
95	18 Jul 09	573014	1427180	87	35	4	กก, บัว	Y
96	18 Jul 09	579728	1429353	44	46	3	กก, บัว	-
97	18 Jul 09	581449	1430100	37	28	3	ธูปถัสน์	Y
98	18 Jul 09	584443	1431337	33	33	3	ธูปถัสน์, บัว	Y
99	19 Jul 09	605714	1415068	5	17	6	ธูปถัสน์, ไมยราบ	Y
100	19 Jul 09	608082	1420261	3	22	4	ธูปถัสน์	Y
101	19 Jul 09	607788	1421435	0	5	3	ธูปถัสน์, บรจ, จู, หญ้า	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
102	19 Jul 09	607861	1422221	3	10	3	ชุปถายี,คกสามเหลี่ยม,ปรง	Y
103	19 Jul 09	592135	1434862	14	17	4	ชุปถายี	N
104	10 Feb 09	604229	1408905	7	14	8	ไมยราบ,คก,บอน	-
105	10 Feb 09	604303	1408965	11	13	8	ไมยราบ	-
106	10 Feb 09	603800	1406645	2	15	8	คก,ไมยราบ,ปรง	Y
107	10 Feb 09	603659	1405730	7	45	7	-	-
108	10 Feb 09	603956	1408153	15	50	9	ไมยราบ,กระบองเพชร	-
109	14 Feb 09	583128	1461578	16	95	10	หญ้ำ,พืชเล็ก,ไมยราบเล็ก,บอ,ตีนตุ๊กแก	Y
110	14 Feb 09	580561	1461177	143	-	9	ตีนตุ๊กแก,ไมยราบดอก,หญ้ำ,ชุปถายี	-
111	14 Feb 09	574815	1456413	76	32	7	หญ้ำ,ไมยราบขี้ขี้,ไมยราบดอกเล็ก,คก,มะระจีน	Y
112	14 Feb 09	603875	1408065	3	-	6	ไม้พุม,หญ้ำ	-
113	15 Feb 09	587372	1443700	40	-	8	-	-
114	15 Feb 09	615896	1440160	1	-	8	-	N
115	15 Feb 09	616858	1440084	1	-	8	-	-
116	7 Mar 09	601077	1461223	-4	64	7	ต้นชู่,ตาตุ่มทะเล,เฟิร์น,แสม,เสม็ด,ชะคราม	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
117	8 Mar 09	596710	1405683	37	95	9	ไมยราบ, หญ้า, ฐปถายี	Y
118	8 Mar 09	596292	1406669	50	91	6	ไมยราบ, ไม้พุ่ม, หญ้า, กระถิน	Y
119	8 Mar 09	596274	1407020	57	90	7	มะขามเทศ, ตำลึง, ไม้เลื้อย, ต้นจุก, หญ้า, สะเดา, ทางนกยูง	Y
120	5 Jul 09	588312	1469067	9	39	8	ฐปถายี, ไม้พุ่ม	Y
121	7 Jul 09	610733	1428202	5	13	3	กระบองเพชร, จุก, หญ้า	N
122	7 Jul 09	610549	1425824	5	17	3	จุก, ไมยราบ, กระบองเพชร, หญ้า	N
123	7 Jul 09	612873	1434277	4	12	3	มะขามเทศ, จุก, กระจ่าง, ไมยราบยักษ์, หญ้า	Y
124	7 Jul 09	613587	1435242	2	21	4	ฐปถายี, กอก, จุก, ไมยราบยักษ์	Y
125	7 Jul 09	602754	1434789	9	29	4	ฐปถายี, ปรัง	N
126	18 Jul 09	584516	1431365	32	35	4	กอก ข่อย หญ้า	Y
127	18 Jul 09	585807	1430621	38	26	3	ข่อย หญ้า	Y
128	19 Jul 09	606785	1417828	0	11	4	จุก หญ้า	N
129	19 Jul 09	610291	1425421	3	21	3	กระบองเพชร, ตาตุ่มทะเล, เสม็ด, จุก, กระจ่าง, หญ้า	N
130	14 Feb 09	580397	1435599	38	35	7	ไมยราบ, หญ้า, ต่อข้าว	Y
131	14 Feb 09	580552	1435538	39	-	7	หญ้า, ต่อข้าว	-

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
132	14 Feb 09	580088	1434599	35	76	7	สะเดา,พีชหนาม,พีชอม่น้ำ	Y
133	14 Feb 09	581133	1430774	34	34	7	กระถิน,ผักนึ่ง,ดอกกรัก,หญ้า,พีชถิ่น,ดอกหญ้า,ข้าว	Y
134	15 Feb 09	595144	1443020	5	26	6	ข้าว,หญ้า,ดอกหญ้า	Y
135	15 Feb 09	592698	1443362	5	-	6	-	-
136	15 Feb 09	591817	1444329	3	29	7	ซังข้าว,หญ้า,ต้นตาล	Y
137	15 Feb 09	607364	1443356	0	12	8	ข้าว,หญ้า	Y
138	15 Feb 09	610775	1440427	1	-	6	-	-
139	7 Mar 09	588815	1467247	-2	0	8	ต้นชู,ต้นตาล,ปอเถียง,หญ้าคา,หญ้าตะกวด,ดอกชบา,ต้นกุ่ม, มะขามเทศ	Y
140	7 Mar 09	584225	1468642	27	35	7	ไมยราบ,ต้นชู	Y
141	7 Mar 09	589893	1467800	0	55	9	ต้นข้าว,รูปถาด,ดอกกรัก,โสน,ต้นลาน,ผักตบชวา,ผักนึ่ง	Y
142	7 Mar 09	600283	1453035	4	53	9	ต้นข้าว,ต้นชู,ไมยราบ,ผักนึ่ง	Y
143	7 Mar 09	601854	1460846	4	60	9	ชู,ชะคราม,แสม,โกงาง,โพธิ์ทะเล	Y
144	16 May 09	588508	1460358	23	26	9	หญ้า,ตีนตุ๊กแก	N
145	16 May 09	588874	1458730	10	7	8	หญ้า	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
146	4 Jul 09	605000	1445500	0	41	10	ข้าว	Y
147	4 Jul 09	606100	1443000	0	36	10	ข้าว	Y
148	4 Jul 09	604100	1452000	0	29	10	ข้าว	Y
149	4 Jul 09	603655	1451031	16	16	8	ข้าว	Y
150	5 Jul 09	581592	1466657	62	59	8	ข้าว	N
151	5 Jul 09	592398	1439331	12	37	8	พวงข้าว	Y
152	7 Jul 09	599057	1433538	5	40	3	ข้าว	Y
153	7 Jul 09	598811	1433745	11	47	3	ข้าว	Y
154	11 Jul 09	579659	1449999	66	36	5	ข้าว	Y
155	11 Jul 09	577472	1449471	65	15	5	ข้าว	-
156	11 Jul 09	578477	1445954	58	21	4	ข้าว	-
157	11 Jul 09	595488	1441988	9	15	5	ข้าว	Y
158	11 Jul 09	590109	1445764	9	11	3	ข้าว	Y
159	11 Jul 09	588465	1445800	27	24	3	ข้าว	Y
160	18 Jul 09	576905	1451672	71	35	4	ข้าว	-

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
161	18 Jul 09	581138	1430384	34	30	3	ข้าว	Y
162	18 Jul 09	581420	1430108	33	84	4	ข้าว	-
163	18 Jul 09	593319	1437736	16	19	5	ข้าว	Y
164	19 Jul 09	607759	1421779	3	7	3	-	Y
165	19 Jul 09	610500	1427786	6	20	3	ข้าว	N
166	19 Jul 09	611352	1430746	2	12	2	ข้าว	N
167	19 Jul 09	612114	1432909	7	15	3	-	Y
168	19 Jul 09	610340	1440664	4	24	5	ข้าว	Y
169	19 Jul 09	608020	1440707	2	14	4	ข้าว	Y
170	19 Jul 09	596779	1441311	9	21	3	ข้าว	Y
171	19 Jul 09	593174	1437093	12	21	4	ข้าว	Y
172	19 Jul 09	595305	1435654	14	22	5	ข้าว	Y
173	10 Feb 09	604496	1402687	18	7	9	จาก, โพธิ์ทะเล, โกงกาง, ต้นแสม, ต้นหญ้าทะเล	Y
174	10 Feb 09	606724	1443905	5	15	9	กก, แสม, ทุปถมิ, บัว	-
175	10 Feb 09	678112	1442886	13	12	9	แสม, โกงกาง	Y

No.	Date	X	Y	Sea level	Slope %	Acc	Vegetation	Grey soil
189	4 Jul 09	615500	1439500	0	24	10	ป่ากอก/แสม, ชะคราม, โพธิ์ทะเล, หญ้า	Y
190	19 Jul 09	607216	1418613	5	16	5	แสม	Y
191	10 Feb 09	614615	1449152	14	11	8	ชะคราม	Y
192	10 Feb 09	608901	1457281	6	29	9	-	-
193	15 Feb 09	587690	1444453	30	-	7	-	-
194	15 Feb 09	615968	1440131	2	9	8	ชะคราม, หญ้า, แสมบาง	-
195	7 Mar 09	608341	1458189	-2	51	7	นาเกลือ	Y

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
1	ดินเหนียว	80	N	N	All year	8	Y	Y	Y	Open Water
2	ดินทรายปนเลน	20	N	N	All year	1	Y	Y	N	Open Water
3	ดินทราย	20	N	N	All year	6	Y	Y	Y	Open Water
4	ดินเหนียวปนทราย	50	N	Y	All year	7	Y	Y	Y	Open Water
5	ดินทราย	50	N	Y	All year	8	Y	Y	Y	Open Water
6	-	-	-	-	-	-	-	-	-	Open Water
7	ดินเหนียว	60	Y	N	All year	50	Y	Y	Y	Open Water
8	ดินเหนียวปนทราย	50	N	N	All year	5	Y	Y	Y	Open Water
9	ดินทรายปนเหนียว	40	N	N	All year	8	Y	Y	Y	Open Water
10	ดินทราย	40	N	N	All year	15	Y	Y	Y	Open Water
11	ดินเหนียว	70	N	Y	All year	1	Y	Y	Y	Open Water
12	ดินทราย	30	N	N	All year	6	Y	Y	Y	Open Water
13	-	-	N	-	-	-	-	-	-	Open Water
14	ดินทราย	50	N	Y	All year	8	Y	Y	Y	Open Water
15	ดินทราย	50	N	Y	All year	14	Y	Y	Y	Open Water

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
16	ดินเหนียวปนทราย	50	Y	Y	All year	7	Y	Y	Y	Open Water
17	ดินเหนียวปนทราย	40	Y	N	All year	11	Y	Y	Y	Open Water
18	ดินเหนียว	40	N	N	All year	9	Y	Y	Y	Open Water
19	ดินเหนียว	40	Y	N	All year	8	Y	Y	Y	Open Water
20	ดินร่วน	50	N	N	All year	10	Y	Y	Y	Open Water
21	ดินร่วน	70	N	N	All year	3	Y	Y	Y	Open Water
22	ดินเหนียว	40	N	N	All year	12	Y	Y	Y	Open Water
23	ดินร่วน	25	N	N	All year	5	Y	Y	Y	Open Water
24	ดินร่วน	25	-	N	All year	3	Y	Y	Y	Open Water
25	ดินร่วน	25	N	N	All year	6	Y	Y	N	Open Water
26	ดินร่วน	25	N	N	All year	10	Y	Y	N	Open Water
27	ดินเหนียว	40	N	N	All year	10	Y	N	Y	Open Water
28	-	-	-	-	-	-	-	-	-	Open Water
29	ดินเหนียว	25	N	N	All year	7	Y	Y	Y	Open Water
30	ดินร่วน	25	N	N	All year	8	Y	Y	Y	Open Water

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
46	ดินร่วน	60	N	N	Season	0	Y	Y	Y	Emerged
47	ดินเหนียว	40	Y	N	Season	0	Y	Y	Y	Emerged
48	ดินเหนียว	60	N	N	Season	0	Y	N	Y	Emerged
49	-	-	-	-	-	-	-	-	-	Emerged
50	-	60	N	Y	Season	0	Y	N	Y	Emerged
51	ดินเหนียว	70	N	N	All year	0	Y	N	Y	Emerged
52	-	-	-	-	-	-	-	-	-	Emerged
53	ดินเหนียว	60	Y	N	Season	0	Y	Y	Y	Emerged
54	ดินเหนียว	60	Y	N	All year	2	Y	Y	Y	Emerged
55	ดินเหนียวปนร่วน	25	N	N	All year	3	Y	N	Y	Emerged
56	ดินเหนียว	40	N	N	All year	1	Y	N	Y	Emerged
57	ดินเหนียว	40	N	N	All year	3	Y	Y	Y	Emerged
58	ดินเหนียวปนร่วน	40	N	N	Season	-	-	-	-	Emerged
59	-	30	N	N	Season	0	Y	Y	Y	Emerged
60	ดินทราย	70	N	N	Season	1	Y	N	Y	Emerged

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
61	ดินเหนียว	60	Y	N	All year	0	Y	Y	Y	Emerged
62	-	40	N	N	Season	0	Y	N	Y	Emerged
63	ดินเหนียว	40	N	N	Season	0	Y	Y	Y	Emerged
64	ดินเหนียว	40	N	N	Season	0	Y	Y	Y	Emerged
65	-	30	N	N	Season	0	N	N	N	Emerged
66	ดินเหนียว	-	Y	N	All year	0	Y	Y	Y	Emerged
67	ดินทราย	40	N	N	All year	0	Y	Y	Y	Emerged
68	ดินร่วนปนเหนียว	70	N	Y	Season	0	Y	N	Y	Emerged
69	ดินเหนียว	40	N	N	All year	1	Y	Y	Y	Emerged
70	ดินเหนียว	30	N	N	All year	1	Y	Y	Y	Emerged
71	ดินร่วน	25	N	N	Season	2	Y	Y	Y	Emerged
72	ดินเหนียว	30	N	N	All year	2	Y	Y	Y	Emerged
73	ดินร่วน	40	N	N	Season	-	Y	Y	N	Emerged
74	ดินเหนียว	50	N	Y	All year	2	Y	N	Y	Emerged
75	ดินเหนียว	50	N	N	All year	0	Y	N	Y	Emerged

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
76	ดินเหนียว	50	N	Y	All year	0	Y	N	Y	Emerged
77	ดินเหนียว	40	N	N	All year	0	Y	N	Y	Emerged
78	ดินเหนียว	30	N	N	Season	0	Y	N	N	Emerged
79	ดินเหนียว	50	N	N	Season	0	Y	N	Y	Emerged
80	ดินร่วน	80	N	N	All year	1	Y	N	Y	Emerged
81	ดินร่วน	40	N	N	All year	0	Y	N	Y	Emerged
82	ดินเหนียว	40	N	N	All year	1	Y	Y	Y	Emerged
83	ดินเหนียว	50	N	N	All year	0	Y	N	Y	Emerged
84	ดินเหนียว	40	N	N	All year	0	Y	N	Y	Emerged
85	ดินเหนียว	70	N	Y	All year	0	Y	N	Y	Emerged
86	ดินเหนียว	70	N	Y	All year	0	Y	N	Y	Emerged
87	ดินเหนียว	80	N	N	All year	1	Y	N	Y	Emerged
88	ดินเหนียว	40	N	N	All year	0	Y	Y	Y	Emerged
89	ดินเหนียว	60	N	N	Season	0	Y	N	Y	Emerged
90	ดินร่วน	40	N	N	All year	1	Y	Y	Y	Emerged

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
106	ดินเหนียว	50	N	N	Season	0	Y	Y	Y	Scrub
107	-	-	-	-	-	-	-	-	-	Scrub
108	-	-	-	-	-	-	-	-	-	Scrub
109	ดินเหนียว	50	N	N	All year	10	Y	N	Y	Scrub
110	ดินทราย	40	N	N	Season	5	Y	Y	Y	Scrub
111	ดินเหนียว	50	N	N	Season	0	Y	Y	Y	Scrub
112	-	-	-	-	-	-	-	-	-	Scrub
113	-	-	-	-	-	-	-	-	-	Scrub
114	-	-	-	-	-	-	-	-	-	Scrub
115	-	-	-	-	-	-	-	-	-	Scrub
116	ดินเหนียว	50	N	Y	All year	3	Y	N	Y	Scrub
117	ดินร่วนปนทราย	40	N	N	All year	1	Y	Y	Y	Scrub
118	ดินร่วนปนทราย	40	Y	N	Season	0	Y	Y	Y	Scrub
119	ดินร่วนปนทราย	50	Y	N	Season	2	Y	Y	Y	Scrub
120	ดินร่วน	40	N	N	Season	0	Y	N	Y	Scrub

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
136	ดินเหนียว	60	N	N	Season	0	Y	N	Y	Farmland
137	ดินเหนียว	60	N	Y	All year	0	Y	N	Y	Farmland
138	-	-	-	-	-	-	-	-	-	Farmland
139	ดินร่วน	20	N	N	Season	0	N	N	Y	Farmland
140	ดินเหนียว	30	N	N	Season	0	Y	N	Y	Farmland
141	ดินเหนียว	60	Y	N	Season	0	Y	N	Y	Farmland
142	ดินเหนียว	40	N	Y	Season	0	Y	Y	Y	Farmland
143	ดินเหนียว	40	N	Y	All year	5	Y	Y	Y	Farmland
144	ดินเหนียว	25	N	N	Season	-	Y	N	Y	Farmland
145	ดินเหนียว	20	N	N	Season	-	N	Y	Y	Farmland
146	ดินเหนียว	50	N	N	Season	0	Y	Y	Y	Farmland
147	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland
148	ดินเหนียว	50	N	N	Season	0	Y	Y	Y	Farmland
149	ดินเหนียว	40	N	N	Season	0	Y	Y	Y	Farmland
150	ดินเหนียว	40	N	N	Season	0	Y	Y	N	Farmland

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
151	ดินเหนียว	40	N	N	Season	0	Y	N	N	Farmland
152	ดินเหนียว	30	N	N	Season	0	Y	N	N	Farmland
153	ดินเหนียว	30	N	N	Season	0	Y	N	Y	Farmland
154	ดินทราย	30	N	N	Season	0	Y	Y	Y	Farmland
155	ดินเหนียวปนทราย	30	Y	N	Season	0	Y	Y	Y	Farmland
156	ดินเหนียวปนทราย	30	Y	N	Season	0	Y	Y	Y	Farmland
157	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland
158	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland
159	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland
160	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland
161	ดินทราย	30	N	N	Season	0	Y	Y	Y	Farmland
162	ดินเหนียวปนทราย	30	N	N	All year	0	Y	N	Y	Farmland
163	ดินเหนียวปนดินร่วน	40	N	N	Season	0	Y	N	Y	Farmland
164	ดินเหนียว	30	N	N	Season	1	Y	N	N	Farmland
165	ดินเหนียว	40	N	N	Season	0	Y	N	Y	Farmland

No.	Soil type	Organic %	Iron	Sulfur	Hydro	Dept (m.)	Water mark	Drift line	Sediment	Type
181	-	-	-	-	-	-	-	-	-	Forest
182	ดินเหนียว	80	N	N	All year	1	Y	N	Y	Forest
183	ดินทราย	80	N	N	Season	0	Y	Y	Y	Forest
184	ดินเหนียว	50	N	N	Season	2	Y	N	Y	Forest
185	ดินเหนียว	80	N	Y	All year	3	Y	N	Y	Forest
186	ดินเหนียว	30	N	Y	All year	1	Y	N	Y	Forest
187	ดินเหนียว	-	N	N	Tideland	0	Y	Y	Y	Forest
188	ดินเหนียว	50	N	N	Tideland	0	Y	Y	Y	Forest
189	ดินเหนียว	50	Y	N	Season	0	Y	Y	Y	Forest
190	ดินทราย	30	N	N	All year	3	Y	Y	Y	Forest
191	ดินเหนียว	20	N	N	Season	0	Y	N	N	Other
192	-	-	-	-	-	-	-	-	-	Other
193	-	-	-	-	-	-	-	-	-	Other
194	-	-	N	N	Season	0	Y	Y	Y	Other
195	ดินเหนียว	50	Y	N	Season	0	Y	Y	Y	Other

BIOGRAPHY

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