Estimation of land use and carbon stocks due to land use change in Phuket Island using GIS and remote sensing

Tip Sophea

A Thesis Submitted in Fulfillment of the Requirement for the Degree of Master of Science in Earth System Science

Prince of Songkla University

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ABSTRACT

Phuket Island, namely the pearl of the Andaman Sea, is one of the most attractive places for tourists. Between 2000 and 2016, the number of tourists coming to Phuket increased four times from 3 million to 12 million people. The growth of the tourism industry in Phuket has resulted in profound shifts to the island, especially to urban development. This urban extension not only causes critical issues such as the deforestation for neighborhood subject, but it also affects to the carbon storage in the soil - one of the main factors which help to mitigate climate change by absorbing CO_2 emissions. Therefore, this study aims to investigate the land use and land cover change, as well as its effect on carbon stocks in Phuket province from 2000 to 2018 by integrating methods: geographic information system (GIS), remote sensing, and estimation of carbon stocks using 2006 Intergovernmental Panel on Climate Change Guideline for National Greenhouse Gas Inventories. Furthermore, this study also estimates the environmental degradation cost caused by the loss of carbon stock using LIME 2. The results of the study show that over a 19-year period, Phuket land use experienced a significant change. A large part of the agricultural area of Phuket has been transformed into tourism facilities such as hotels, restaurants, and resorts. From 2000 to 2007, rubber plantations in Phuket decreased by 10 % and it kept decreasing by 1-2 % till ended period of study. Meanwhile, the settlement area increased by 2-4% in every period of study timeline. Forest land, under the effect of government policy, increased 7% during 2000-2007. After 2007, the forest area fluctuated around 23-24% of the total Phuket area. The loss of carbon storage has been alleviated mainly due to government policy such as the land-reform scheme and National Mangrove Rehabilitation Project to protect the forest and delay the land-use change. Consequently, the total carbon stock in Phuket slightly declined by approximately 1% over 19 years. This environmental loss (1% of carbon stock reduction) is equivalent to around 9 million USD.

Keywords: carbon stocks, GIS, land use changes, Phuket, remote sensing

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LIST OF ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
AGC	Above-ground Carbon
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BGC	Below Ground Carbon
CH_4	Methane
CO_2	Carbon Dioxide
CVA	Change Vector Analysis
DOM	Dead Organic Matter
EPA	Environmental Protection Agency
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
GHGs	Greenhouse Gases
GIS	Geography Information System
GPP	Gross Provincial Product
GPS	Global Position System
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISET	Institute for Social and Environmental Transition
LDD	Land Development Department
LIME	Life Cycle Impact Assessment Method based on Endpoint Modelling
NDVI	Normalized Difference Vegetation index
N_2O	Nitrous Oxide
PCA	Principle Component Analysis
PPSO	Phuket Provincial Statistic Office

LIST OF ABBREVIATIONS (Continued)

RS	Remote Sensing
THEOS	Thailand Earth Observation System
SEEK	Society Environment Economy & Knowledge
SPOT	Satellite Pour l'Observation de la Terre
SNAP	Sentinel Application Platform
USD	United State Dollar
USGS	United States Geological Survey
UTM	Universal transfer Mercator
WGS	World Geodetic System
N/A	Data are not available

CHAPTER 1

INTRODUCTION

1.1 Problem statement

Climate change is one of the serious environmental concerns that human is facing recently (Osman and Sevinc 2019). This global problem has resulted in numerous adverse impacts, not only on human well-being but also on the other species' existence (Hart and Feldman 2018). For instance, climate change can exacerbate severe weather conditions (Prăvălie 2018) such as prolonged droughts, heavy flood; leading to food insufficiency (Li et al. 2019) and health problems for human (Uyttendaele et al. 2015), and habitat loss due to the change of living environment for plant and animals (Zhao et al. 2019). The increase in the carbon dioxide (CO_2) concentration in the atmosphere is attributed to be the main reason that causes global warming, and then, climate change (Florides and Christodoulides 2009); while 40 % of this increase is due to human activities (Shukla et al. 2017).

In the last 30 years, human activities have caused extensive alteration on the natural environment, especially through land use change - one of the main sources of greenhouse gas (GHG) emissions (Fearnside 2000). Alteration in land use can have huge impacts on the carbon cycle which varies the carbon stock in soil patterns and causes the growth of GHGs in the atmosphere (Ribeiro et al. 2016). Moreover, land use change also influences the area of forest - the most important carbon removal factor in the Earth that helps reduce the significant amount of CO_2 emissions. Forest is able to decarbonize the atmosphere and store in soil 25% of the total annual carbon emissions caused by economic activities (Prăvălie 2018). Therefore, with the ongoing concern about climate change, the effect of land use change on GHG emissions transferred from carbon storage in soil should be investigated (Petsri et al. 2013).

As one of the global largest industries, tourism has stimulated the economic development of many areas in the world. One of them is Phuket. Different from Bangkok - the most famous tourist attraction based on urban tourism, being at the second rank, Phuket is popular for its coastal tourism. Around 30% of the total number of visitors coming to Thailand was recorded traveling to Phuket province (Torres Chavarria and Phakdee-auksorn 2017). In 2015, tourism generated nearly 9,790 million USD which brought Phuket to be the province with the highest gross provincial product (GPP) in the Southern region of Thailand (Phuket Provincial Statistic Office 2018). As a response to the growing number of tourists, many developments and changes can be seen in Phuket. For instance, in 2016, the Phuket International Airport extended a new terminal in order to increase the capacity of tourist reception (Netherlands Embassy in Bangkok 2017). Furthermore, Phuket's landscape has been transformed significantly from spacious vegetation areas into a mass tourist destination such as hotels, restaurants, resorts, shopping centers, and road (Marzuki 2012; Thailand Property 2014). As a result, forest and agriculture areas decreased slightly over 14% from 2000 to 2009. Many hotels were built in those areas, especially in hillsides where are expedient for sightseeing (Boupun and Wongsai 2012). This can simply conclude that tourism is a key factor impacting the carbon cycle between land surface and atmosphere due to the loss of forest. As mentioned earlier, the changes in land use could increase CO_2 - a major GHG causing climate change (Sakalli et al. 2017). On the other hand, the climate change can cause several impacts on Phuket Island. For instance, the infrastructure, beaches, coral reefs might be damaged by natural hazards such as rainstorms and typhoons or beach can be destroyed by the rise of sea level (Phuket 2013).

In order to support the effort of mitigating climate change and stimulate tourism development, it is important to take into consideration land use change in the process of establishing a policy of natural resource management. Information about land use change could reveal how the forest, agricultural area, and urban area have been being used over the past time which might reflect terrestrial carbon changes. This can provide useful trends of historical land use change for future land use planning, especially for the area which is affected strongly by tourism development such as Phuket. Therefore, this study aims to analyze land use change during the period from 2000 to 2018, as well as quantify dynamic variation of terrestrial carbon stocks in response to land use change in Phuket to provide necessary evidence for decision-makers to introduce a better land use planning.

1.2 Research objectives

- To generate a new Phuket land use map in 2018 in order to get recent land use information
- To analyze land use change during the period from 2000 to 2018
- To estimate variation of terrestrial carbon stocks in response to land use change

1.3 Research scope

This study is carried out in the following scope:

- Including:
  - Land-use and carbon stock changes in Phuket: during the period between 2000 to 2018
- Excluding:
  - The age of vegetation was not taken for consideration because it cannot be determined by land use data

CHAPTER 2

LITERATURE REVIEW

In this research, several methods are used to observe the land use changes and then calculate carbon stock. First, land-use change is investigated by using geography information system (GIS). Therefore, the linkage between tourism development and land use are introduced in the first section of this chapter then GIS for investigation of land use change is reviewed from various studies to find out the appropriate technique. Second, in order to get recent information about Phuket, RS data (satellite data) are used to make a new land use map of Phuket (2018). Hence, the concept of RS is introduced; after that, types of remote sensing (RS) data are reviewed to choose appropriate data and techniques for producing new land use map. Lastly, 2006 IPCC guideline is introduced.

2.1 Tourism development, land use change, and environmental consequences

Tourism is a key contributor to the global economic growth (Greco et al. 2018) and also the main contributor to GHG emissions (Tsai et al. 2018). Typically, there are two primary determining forces of tourism carbon emissions: one relates to travel activities and the other relates to the production process from the supply chain (Sun 2016). Furthermore, the development of tourism provokes changes in land use in tourist areas, which affect either directly or indirectly to the local environment (Mao et al. 2014). For example, some anthropologic activities such as sand mining, beach and sand erosion, soil erosion, and extensive paving are caused by tourism developments (e.g., accommodation, water supplies, restaurants, and so on). Also, constructions of infrastructure such as road and airports can impact green area, wildlife habitats and scenery (Sunlu 2003). In conclusion, fast development for tourism could lead to changes in land use which can affect the functions of an ecosystem (Mao et al. 2014) as well as in carbon storage in land (Tsai et al. 2018).

2.2 Land use concept

Basically, land use refers to how land is being used by humans for different purposes. Nature of land use is dynamic. It has been changing from year to year. Land-use change could be seen at spatial scales from local to global at temporal frequencies of days. Both human activities (e.g., conversion of forest area to an agricultural area and urbanization) and natural phenomena (e.g., glaciation, continental drift, flooding, and tsunamis) are main factors causing the changes of land use. In recent decades, human activities cause land use change much more than natural phenomena. As a result, an unprecedented rate of change has become a major environmental concern worldwide (Brown et al. 2013).

2.3 Techniques for land-use change investigation

Change detection technique is a method to identify the changed areas in the multi-temporal spatial data. Accurate change detection of Earth's surface characteristic provides essential information for a better understanding of environmental change. Various procedures of change detection techniques have been developed, so the appropriate technique should be carefully selected to produce a high-quality result (Lu et al. 2004). Some techniques are possible to provide the change and non-change information only, while others can provide a complete table of change areas. Sagnika et al., (2014) reviewed multispectral change detection techniques and categorized into six groups: (1) algebra-based approach, (2) transformation, (3) classification, (4) advanced models, (5) visual analysis, and (6) GIS and RS.

2.3.1 Algebra-based approach

The algebra-based approach uses the threshold of images over a specific period of time to determine the change areas. These methods are simple to implement and easy to interpret; however, the challenges of these methods cannot provide the detail information of the change areas (Bhavani et al. 2018; Lu et al. 2004). The different subgroups of the algebra-based approach used for change detection in image processing are image differencing, image rationing and Change Vector Analysis (CVA).

2.3.1.1 Image differencing

Image differencing technique, as shown in Figure 2.1, is the subtraction of pixel value of two images in a specific area with different time. The technique is simple and easy to implement but the same value may have different meaning because value is absolute (Khanday and Kumar 2016). It can only identify the change and no-change area.

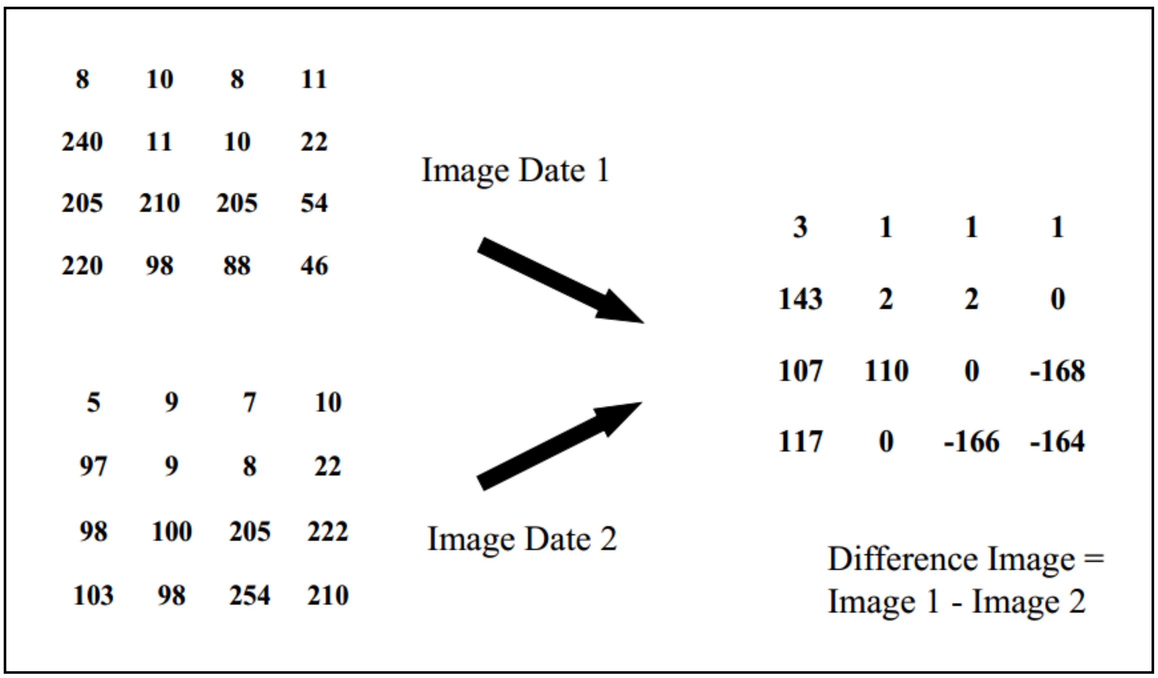


Figure 2.1 The image differencing concept (Khanday and Kumar, 2016)

2.3.1.2 Image rationing

Similar to Image differencing, Image rationing is also a simple and rapid process to identify changed areas. This technique makes the comparison of two images from different dates. The result of Image rationing is unable to provide complete information of change areas as a matrix table. It just provides change and no-changed areas. In terms of no-change areas, the ratio value is one, while the ratio value greater or less than one is determined as changed areas (Al-doski et al. 2013).

2.3.1.3 Change vector analysis

CVA is a technique which is able to simultaneously analyze of diverse image bands (Ilsever and Ünsalan 2012). The CVA generates two outputs change information described by the magnitude and direction of the image from two input image bands. The length of the vector illustrates the magnitude of change whereas the direction illustrates the nature of change (Bhavani et al. 2018)

2.3.2 Transformations

Transformations including principal component analysis (PCA), Kauth-Thomas (KT), and Gramm-Schmidt (GS) are methods used to reduce the redundancy of data by suppressing correlated information (Tewkesbury et al. 2015). However, the disadvantage of this method is the same as the Algebra-based approach that the details of the change matrix cannot be revealed (Santawana et al. 2015)

2.3.3 Classification-based approach

Classification-based approach includes post-classification comparison, spectral-temporal combined analysis, unsupervised classification, and hybrid classification. These methods depend on the classification of the image and the training sample data for producing high-quality classification results. The advantage of these methods provides the matrix of change area information; however, the accurate training sample and time-consuming is the challenge tasks of this method (Lu et al. 2004; Santawana et al. 2015)

2.3.4 Advanced models

In case of advance models, the reflectance value of the image is converted to the physical-based parameters. The transformed parameters are more convenient to interpret and extract information than a spectral signature, but the disadvantage of these models is time-consuming during processing. The advanced model change detection method category includes biophysical parameter model, and spectral mixture models (Lu et al. 2004; Santawana et al. 2015)

2.3.5 Visual analysis

This method is not often used because it is based on the analyst's experience through texture, shape, size, and pattern of images for identifying the changed area. Also, it could not provide the change information trajectories. In fact, the visual analysis method is frequently used before 1970s when the satellite data had not been provided. Since satellite data are available, this method is no longer popular (Lu et al. 2004; Santawana et al. 2015)

2.3.6 GIS and RS techniques

GIS methods are used overlaying of GIS layer on images to identify the changed area. The advantage of the GIS method could provide detailed information about the changed area matrix and take a short time for processing (Lu et al. 2004; Santawana et al. 2015).

In conclusion, all the techniques of land use change study have advantages and disadvantages. The most appropriate technique for this research could be GIS because this method could show the transition of change areas and the process requires shorter time than other techniques.

2.4 GIS concept

GIS is defined as a technology for spatial data management, which includes hardware and software providing input, storage, processing, analysis, and visualization of spatial data (Zhuk et al. 2016). The history of GIS was begun during the 1960s when the software on mainframe computers was used to perform various computational tasks (Dixon and Uddameri 2016). During that period, several scientists started to find out whether computer machines could be used to draw maps. In 1966, the first GIS was developed by Canadian Geographic System when an aerial surveyor, Richard Tomlison completed a large survey portion of Eastern Africa and realized the need of mapping system (Dixon and Uddameri 2016). Due to the necessity of GIS, the majority of spatial data companies focused on developing all aspects of GIS including software, consultation, and data collection. In 1969, Environmental System Research Institute (ESRI), the most successful company of GIS, founded by Jack Dangermond and his wife, Luara, in California, was the first land use consulting firm with the mission to support the land use planner decision by organizing and analyzing geographic information (Environmental System Research Institute 2015). To perform analysis of hundreds of projects more effectively, in 1982, ESRI released the first commercial program of GIS, ArcInfo, which represented geographic features as points, lines, and polygon with attributes information. Since that year, the GIS program has been updating up to now by ESRI (Environmental System Research Institute 2015).

2.5 GIS for land-use changes studies

GIS has been widely used to investigate land-use change. Rawat and Kumar (2015) conducted a study on land-use/cover change in Uttrakhand, India from 1990 to 2010 by using GIS and RS techniques. Authors used the Landsat Thematic Mapper data in 1990 and 2010, available on the Global Land Cover Facility Site and Earth explorer platform. Then the authors made classification into five classes namely agriculture, vegetation, barren, water body, and built-up area by employed Supervised classification method. After classification was performed, the authors analyzed the land-use change by employed post-classification which made comparison base on pixel. The results surprisingly showed that over the last two decades vegetation and build up area had been increased by approximately 4% while bare land and water body decrease by 2% and 5%, respectively. Butt et al., (2015) observed the land-use change in Simly watershed in Pakistan in 1992 and 2012 by using GIS and RS. Earth observation data Landsat 5 was used to produce land use map in 1992 and satellite data SPOT 5 was applied to make land use map in 2012. Then post-classification technique comparing pixel-by-pixel was employed to check the land use change in Simly watershed. The result indicated that vegetation areas and water body were transformed into agricultural areas and settlements approximately 38% and 74%, respectively.

2.6 GIS for land-use change studies in Phuket

Boupun and Wongsai (2012) conducted a land-use change and the town planning policy of Phuket. The data used to conduct this study were Phuket Town Planning Policy map in 2005 getting from the office of Public Works and Town Planning Phuket and land use map of Phuket in 2009 from Land Development Department (LDD), Ministry of Agriculture and Cooperatives of Thailand. Then overlay technique was employed to observe the change areas. The results depicted that forest and agricultural areas were transformed into residential areas about 4% and 11%, respectively, and many hotels were built in the hillside where enable visitors to enjoy sea sightseeing. Payakka and Wongsai (2012) conducted a historical land-use/cover change by utilizing Landsat series satellite imagery and Thailand Earth Observation System (THEOS) satellite data in Phuket from 1989 to 2011. After that, those images were classified into 12 categories by using the Supervised classification, followed by overlay change detection techniques. The results of the study showed that over the past 22 years (1989-2011) built-up area largely increased and forest conservation areas decreased approximately 30 km^2. Prueksakorn et al. (2018) carried out a research to estimate the soil organic carbon stock from land use change in Phuket. The LDD land use datasets in 2000, 2009, and 2013 were converted to the unique coordinate system, World Geodetic System 1984 (WGS1984). After that, land use classifications were regrouped into eleven groups. Subsequently, Tabulate area method was used to observe the change areas. As a result of the study, the authors found that built-up areas are significantly increased from 80.4 km^2 to 133.0 km^2 between 2000 and 2013. They also emphasized that the change of land use in Phuket corresponds with development plan, i.e., fourth national economic and social development plan (1977–1981) which turned Phuket from mining industry to tourism industry.

2.7 RS concept

RS is defined as the practice of information acquisition without touching on Earth’s land and water surfaces by using images from space that use electromagnetic spectrum reflected or emitted from the Earth's surface (Campbell and Wynne 2011). Some daily activities including reading articles, watching television, or looking at computers are all RS activities of human eyes. Human eyes can see those objects because of solar radiation reflection and they are interpreted as information by the brain. However, our eyes can detect the objects in a small part of electromagnetic spectrum ranging approximately from 400 to 700 nm as shown in Figure 2.2 (De Jong and Van Der Meer 2005). In RS technology, various optical sensors were equipped to obtain more information which is an invisible range of human eyes such as Infra-Red (IR) and Microwave (De Jong and Van Der Meer 2005). RS has several types of data but the most common use is satellite imagery.

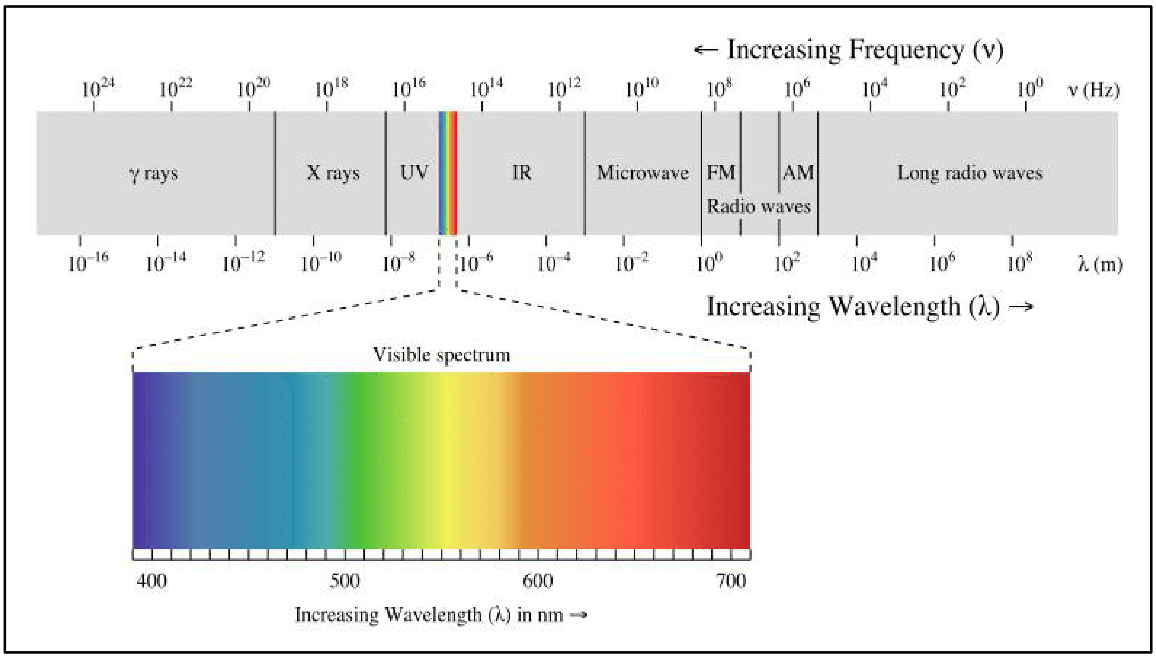


Figure 2.2 The visible electromagnetic spectrum of human eyes (Weerasinghe 2016)

2.8 Satellite imagery

Satellite imagery provides essential information to numerous fields such as natural resource management, natural disaster management, weather prediction, etc. In 1957, the first satellite, called Spuntik 1, was officially launched by the former Soviet Union in Earth's orbit (Cracknell and Varotsos 2007). Another reconnaissance satellite, Corona, was launched by USA in 1960 (Rhyma et al. 2016). Both Spuntik 1 and Corona were used for military purposes at that time.

During the 1970s, the era of Earth observation satellite commenced, and Landsat 1 was the first Earth observation satellite launched by the USA, in 1972. Until 1986, the first commercial satellite, SPOT 1, was launched. Commercial satellite such as QuickBird, Ikonos, and SPOT provide high-resolution images is convenient and accurate for interpretation, but it is quite expensive (Rhyma et al. 2016). There are two types of earth observation satellite: passive optical sensor satellite which require the electromagnetic wave of sun radiation to capture the objects, and active sensor satellite which use their energy to illuminate for capturing the objects (Rhyma et al. 2016).

Table 2.1 summarizes the Earth observation satellite in the past 3 decades.

Name of satellite	Number of bands	Spatial resolution (m)	Launch date	Application status
Landsat 1	4	80	1972	Inactive (1996)
Landsat 2	4	80	1975	Inactive (1996)
Landsat 3	4	80	1978	Inactive (1996)
Landsat	6	30	1984	Inactive (1996)
SPOT 1	3	20	1986	Inactive (2002)
SPOT 2	3	20	1990	Inactive (2009)
SPOT 3	3	20	1993	Inactive (1996)
SPOT 4	4	20	1998	Inactive (2013)
Landsat 7	6	30	1999	Inactive (1996)
ASTER	10	15	1999	Active
IKONOS	4	4	1999	Inactive (2015)
QuickBird	4	2.4	2001	Active
Landsat 8	11	30	2013	Active
Sentinel-1	Microwave	5	2014	Active
Sentinel-2	13	10	2015	Active
Sentinel-3	21	300	2016	Active

Source: (Rhyma et al. 2016)

2.9 RS in Land use

After Earth observation satellite has been launched, RS has been increasingly used in environmental fields such as agriculture crops, water quality, urbanization, land use, etc. RS helps us to understand the ecological system and behaviors of animals and to measure the ozone hole size in the atmosphere as well as to forecast the weather. Regarding land use, RS is very useful to estimate areas. RS can provide detail spatial information in the temporal area including the remote area which is inaccessible (De Jong and Van Der Meer 2005). Previous RS data also can be obtained; therefore, past time-series of land use can be observed and reconstructed through classification. However, the challenge of RS is that the result might be affected because of the change of weather, particularly when making a comparison of RS data over periods (IPCC 2006).

2.10 GHGs emission

GHGs, absorbing the radiation of solar and keeping the earth warm enough to live, is considered to be a natural part of the atmosphere. Since the industrial revolution, however, anthropogenic GHG emissions have driven large increases in the atmospheric concentrations of CO_2, methane (CH_4), and nitrous oxide (N_2O) (IPCC 2014). Burning of fossil fuels including coal, oil, gas, or peat can emit CO_2 into the atmosphere. This emission process is done through poor land management and land-use change such as deforestation and urbanization. Also, it is known that the agriculture sector such as manure management, livestock, and fertilizer application can make the main source of CH_4 and N_2O release to the atmosphere (Environmental Protection Agency 2018).

2.11 2006 IPCC Guidelines for National Greenhouse Gas Inventories

2006 IPCC Guidelines, the result of the work of over 250 authors in 2 years, were reviewed carefully by experts and governments before IPCC accepted. The 2006 Guidelines are a significant step forward in the production of high-quality national estimates of emissions and removals of GHGs. In this guideline, there are five volumes:

- Volume 1 - General Guidance and Reporting: provides fundamental information on inventory compilation and guidance on the choice of methods.
- Volume 2 - Energy: refers to the use, production and transport of energy which includes coverage of CO_2 capture and storage.
- Volume 3 - Industrial Processes and Product Use (IPPU): covers industrial processes such as petrochemicals, metal production, and other chemical production as well as the use of products including fluorinated gases.
- Volume 4 - Agriculture, Forestry, and Other Land Use (AFOLU): covers agricultural sources including livestock, manure management, and fertilizer use as well as emissions and removals of GHGs from different land uses such as grasslands, forestry, and settlements.
- Volume 5 - Waste: refers to the collection, treatment, and disposal of wastes (e.g., solid wastes, landfills, and wastewater treatment).

2.12 2006 IPCC Guideline-Volume 4

2006 IPCC Guideline-Volume 4 contributes the guidance of annual GHGs inventories in AFOLU sector. It indicates that land-use changes can release GHGs from terrestrial carbon stocks.

a). Carbon pools used in AFOLU

According to IPCC, there are five carbon pools of a terrestrial ecosystem involving biomass, namely the above-ground biomass, below-ground biomass, deadwood, woody debris/litter, and soil organic matter. The definition of each carbon pool defined by IPCC is shown in the table below.

Table 2.2 Categories and definition of carbon pools

Definitions of carbon pools		
Pool		Description
Biomass	Above-ground biomass	Above-ground biomass includes all living vegetation above the soil such as branches, stems, stumps, bark, and foliage.
	Below-ground biomass	Because roots cannot frequently be differentiated from soil organic matter or litter, the diameter of these roots with less than 2 mm is not often included.
Dead organic matter (DOM)	Deadwood	Deadwood includes wood with a diameter larger than or equal to 10 cm which lies on the surface, dead roots, and stumps.
	Litter	Litter includes all non-living biomass with a diameter ranging from 2 mm to 10 cm in different decomposition states above or within the organic soil and mineral.
Soils	Soil organic matter	Soil organic matter includes organic carbon in mineral soils to a specified depth chosen by the country. Both living and non-living fine roots and DOM within the soil with 2 mm in diameter for roots and DOM are included with soil organic matter.

Source: (IPCC 2006)

b). Land use and management categories

To prepare inventories for the AFOLU sector, emissions and removals of CO_2 and non-CO_2 GHGs are estimated separately for each of six land-use categories as following:

Table 2.3 Definition of land-use categories following 2006 IPCC guideline

Categories of Land-use	Description
Grassland	Grassland includes pasture and rangelands which are not regarded as Cropland. This category also includes vegetation systems and other non-grass vegetation (e.g., herbs, brushes, recreational areas, and silvi-pastural systems).
Wetlands	This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It also includes reservoirs, natural rivers and lakes.
Settlements	Settlements refer to urban land or all developed land including infrastructure, human settlements of any size unless they are already included under other categories.
Other Land	This category includes ice, bare soil, rock, and all land areas that do not fall into Forest land, Cropland, Grassland, Wetlands, and Settlements.
Forest land	This category includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national GHGs inventory.
Cropland	This category includes cropped land, including rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.

Source: (IPCC 2006)

c). Tier methods in AFOLU

To estimate the GHGs in AFOLU sector, the 2006 IPCC guideline (volume 4) provides three tiers of method:

Tier 1: methods are designed for simple usage. All equations and default emission factors are provided in the 2006 IPCC guideline (volume 4). Global data can apply if emission factors in the guideline are not available.

Tier 2: similar to Tier 1 but parameter value (emission factors) are derived based on country/region-specific.

Tier 3: Unlike Tier 1 and 2, Tier 2 requires higher-order methods for calculations. It includes field sampling redone at a regular time interval or GIS-based systems of age, soil data, class/production data, land use data, and activity data management.

CHAPTER 3

METHODOLOGY

In this chapter, the process of methodology is described as the following contents:

- Study site description (includes elevation, and climate of Phuket)
- Data source description
- Research process

3.1 Study site description

3.1.1 Phuket administration

Phuket is the largest island and a popular tourism site in Thailand. It is situated between North latitude 7°45′-8°15′ and Earth longitude 98°15′-98°30′. The total land area of Phuket is approximately 546 km^2, stretches about 48 km from the North to South and 21 km width. The administrative boundary of Phuket is divided into three districts, Thalang, Muang, and Kathu (as shown in Figure 3.1) with the total residents 392,011 people or 240,844 families in 2016 (NSO, 2017).

Most of the area in Phuket island (approximately 70%) is covered by mountains stretching from North to South, and 30% of flat plain areas, mainly in the middle and eastern parts of the island (Saowanee et al. 2012). It can be seen that the highest elevation of topography is located in the western and northeastern part of Phuket Island with the elevation value >80 m, while it can be seen that the lowest elevation ranging from 20 to 60 m is located at the northern and southeastern part of the Island.

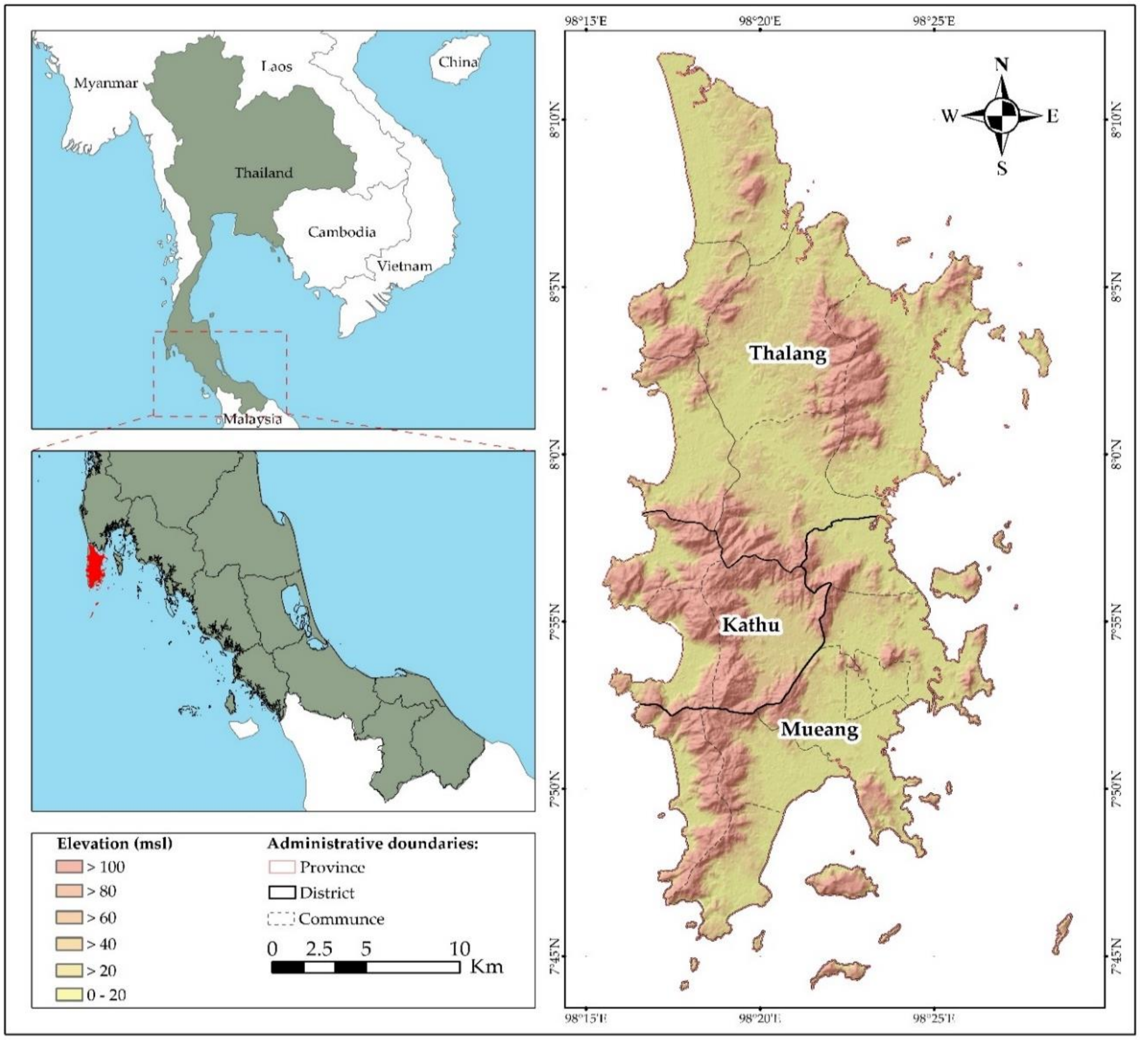


Figure 3.1 Map of the study area, Phuket province.

3.1.2 Phuket climate

Tropical monsoon enables Phuket's weather warm and humid all year round with two seasons. The rainy season lasts from May to November and the rest is a dry season. The average annual rainfall in Phuket is around 2 thousand millimeters. The period from November to October has the highest rainfall amount, approximately over 300 mm per month (Figure 3.2) with average rainy days almost three weeks a month. Directly hit of Southwest monsoon make Phuket more abundant rain than the other coast of peninsular Thailand (World Climate Guide, 2017).

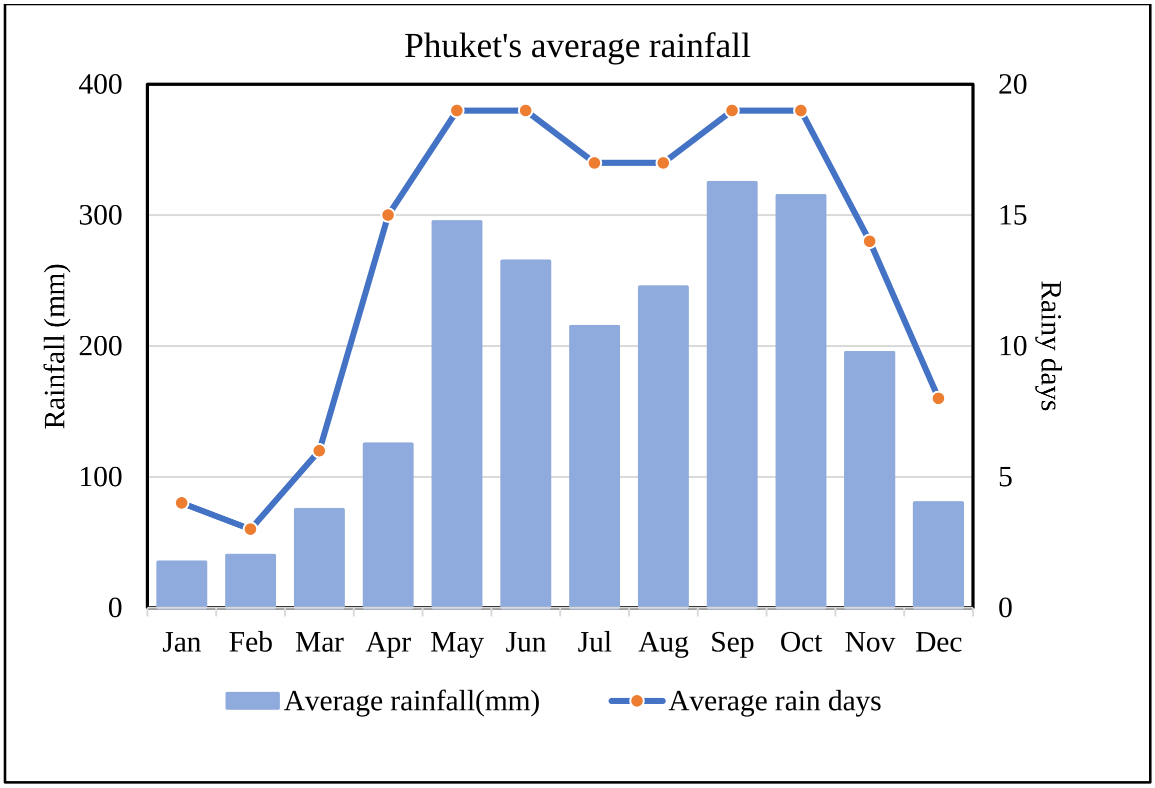


Figure 3.2 The average rainfall in Phuket (World Climate Guide 2017).

3.2 Data source description

This study used two different sources of secondary data, (1) Satellite data, Sentinel-2, and (2) datasets of Phuket land use data from LDD. The Sentinel-2 satellite data acquired in March 2018 was used to produce a land use map of Phuket in 2018. This satellite is free and available on European Space Agency platform

Datasets of Phuket land use (2000, 2007, 2009, 2013, and 2016) were obtained from LDD, Ministry of Agriculture and Cooperatives of Thailand. All these available datasets were mainly used for analyzing the land use change in Phuket. As shown in Table 3.1, the coordinate system and number of classes of all land use data are different (especially for the coordinate system of year 2000) due to the limit of data availability.

Table 3.1 LDD Phuket Land use datasets information

Year of land use	Coordinate system	Number of classes	Source of data
2000	Indian 1975	40 Classes	LDD, Ministry of Agriculture and Cooperatives of Thailand
2007	WGS1984	43 Classes	
2009		53 Classes	
2013		60 Classes	
2016		85 Classes	

Source: LDD, Ministry of Agriculture, and Cooperatives.

3.3 Research framework

The study of land use change and carbon stocks assessment in Phuket consists of four main steps as presented in Figure 3.3. First, land use/land cover classification of Phuket in 2018 was made using Sentinel-2 satellite data. Then this land use/land cover map (2018) was used to combine with the secondary data (from LDD) to examine the change of areas in Phuket over 19 years (from 2000 to 2018). Afterward, the 2006 IPCC Guideline was used to estimate the carbon stocks in Phuket. In the last step, the environmental degradation cost of CO_2 from land use change was estimated. The details of each process are described in the sections below.

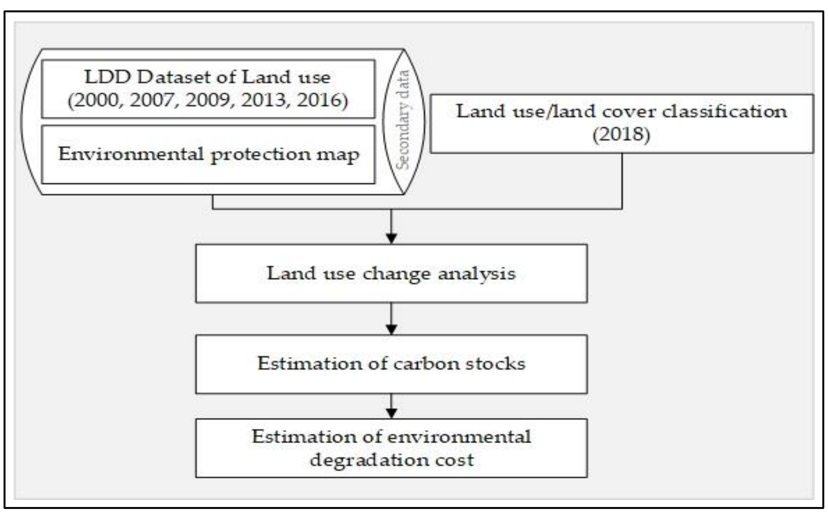


Figure 3.3 The research methodology flow chart.

3.3.1 Land use/land cover classification of Phuket (2018)

Land use/land cover classification of Phuket was produced through main four processes; (a) Input data, (b) Preprocessing, (c) Classification, (d) Accuracy assessment (as shown in Figure 3.4).

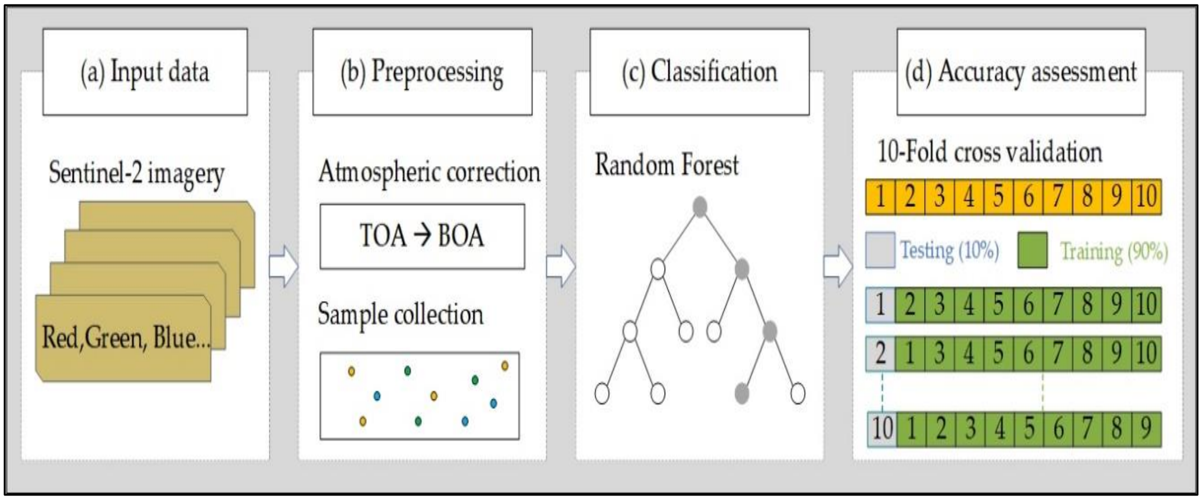


Figure 3.4 The research methodology of land use/land cover classification

(a) Input data

To produce land use/land cover map of Phuket, the cloud-free image of Sentinel-2, acquired on 26 March 2018, was downloaded from Copernicus Open Access Hub. Sentinel-2 is a multispectral instrument that has been launched by the European Space Agency since 2015. This satellite data consists of 13 spectral bands with three different spatial resolutions: four bands at 10 m, six bands at 20 m, and three bands at 60 m (ESA 2015). There are two weak conditions of satellite imagery, i.e., terrain profile, and atmospheric conditions (Huang et al. 2018). Terrain profile refers to the bias illumination of images cause by different land surface topography and sun angle during sensor capture (Huang et al. 2018; Pons et al. 2014). Atmospheric conditions are the influences of water vapor and aerosols on the reflection of the solar or emitted radiation by an object at the land surface during the satellite sensor image detection (De Jong and Van Der Meer 2005). To avoid these undesired effects, preprocessing is needed to amend the data before usage.

(b) Preprocessing

In this study, the imagery was preprocessed using an atmospheric correction processor, called Sen2Cor. Sen2Cor is a Sentinel-2 Level 2A processor that was created to correct single-date of Sentinel-2 Level-1C (Top-Of-Atmosphere) products from the effects of the atmosphere, generating better quality products, called Level-2A (Bottom-Of-Atmosphere) (Main-Knorn et al. 2017).

Before performing the supervised classification, a reference dataset is required to be collected. It allows the algorithm to learn the relation between the pixel values of the different bands in an image and categories of land use/land cover class (Gómez 2017). The rule of thumb which was recommended by Congalton in 1991 suggested that a minimum of 50 samples per category should be collected if the number of classifications is less than 12 categories or the study areas is less than 4,000 km^2. However, it also could be adjustable which commensurate with the importance of each land use/land cover category (Carste Haub and García Millan 2015). In this study, the total number of 880 samples was collected from the field using a stratified random sampling approach (the locations of data were shown in Table A4.11 of Appendices). The number of classifications was 13 categories; however, during the field data collection, the areas of paddy field were too small and some of them already transferred to the other categories of land use, so this category was manually classified. The appearance of Grassland and Shrubland was very similar. The guidance of IPCC indicated that shrublands might consider as a type of grassland and countries may elect to account for some or all of these shrublands in the Grassland category (IPCC, 2006). But in Phuket, Grassland and Shrubland were functional in different ways. Mostly, Shrublands was occupied by someone; in contrast, Grassland was un-used land. To reduce the error of land use/land cover classification, Shrubland was manually classified by field observation and Google Earth Pro 2018. Other two categories, Reservoir, and Other land, were masked out in the same pattern as previous land use in 2016. Therefore, the remaining number of classifications was eight categories: Mangrove forest, Other forest, Rubber, Other agricultural area, Golf course, Grassland, Water body, Aquaculture, and Settlements.

(c) Classification

To performed land use/land cover classification, pixel-based supervised classification was used with Random Forest classifier in SNAP application. Random Forest is a machine learning algorithm which consists of multiple decision trees. Each decision tree is created by a different subset of training samples to produce a diversity of trees through replacement (bagging approach). From the various outputs of each decision tree, the output class is obtained as the majority vote (Belgiu and Drăgu 2016; Immitzer et al. 2016). Random forest uses about two-thirds of samples to train the trees (called in-bag-samples) while the remaining ones (called out-of-bag samples) are used as internal cross-validation to estimate how well of Random Forest performs (Belgiu and Drăgu 2016; Čeh et al. 2018). Two input parameters of Random Forest are required to be defined: the number of trees, and the number of features used in each split of the decision tree. Several studies indicated that default parameters of Random Forest often provide satisfactory results (Belgiu and Drăgu 2016; Immitzer et al. 2016; Noi and Kappas 2018; Zhang and Roy 2017). Hence, the default values were used in this study by setting the number of trees to 500 trees and the default number of features was the square root of the total number of input features.

(d) Accuracy assessment

Accuracy assessment expresses the quality of the map from a comparison between classification results and reference data. In this study, the 10-fold cross-validation technique was used to validate the classification result. The 10-fold cross-validation splits the reference data (ground truth data) randomly into 10 sub-datasets (each sub-dataset consists of 10% of each sample class) (Immitzer et al. 2016). In each classification, Random Forest permutable used 90% of reference data as training data and the remaining data (10%) was used as testing data (validate data). This step was iterated ten times. In the end, the accuracy assessment was presented as one confusion matrix of the ten results of the cross-validation.

3.3.2 Land use change

This section comprises two parts, (i) assessment of land use change in Environmental protection area, and (ii) assessment of land use change in Phuket from 2000 to 2018.

3.3.2.1 Land use change in the environmental protection area

The Settlement area of Phuket land use/land cover map in 2018 was used to overlay with the Environmental protection area to observe the changed area in the forest conservation zone. Environmental protection map was first georeferencing within World Geodetic System (WGS) 1984 zone 47N coordinate system. Then the conservation boundaries of forest were digitized and converted as Raster data with the cell size 10 m x 10 m (100 m^2). After that Map algebra technique was used to detect the changed areas in the conservation zone. Another fieldwork was also conducted again to verify the changed areas using waypoint on GPS to search the dropped pin location of change areas. The processes of this change detection are presented in Figure 3.5.

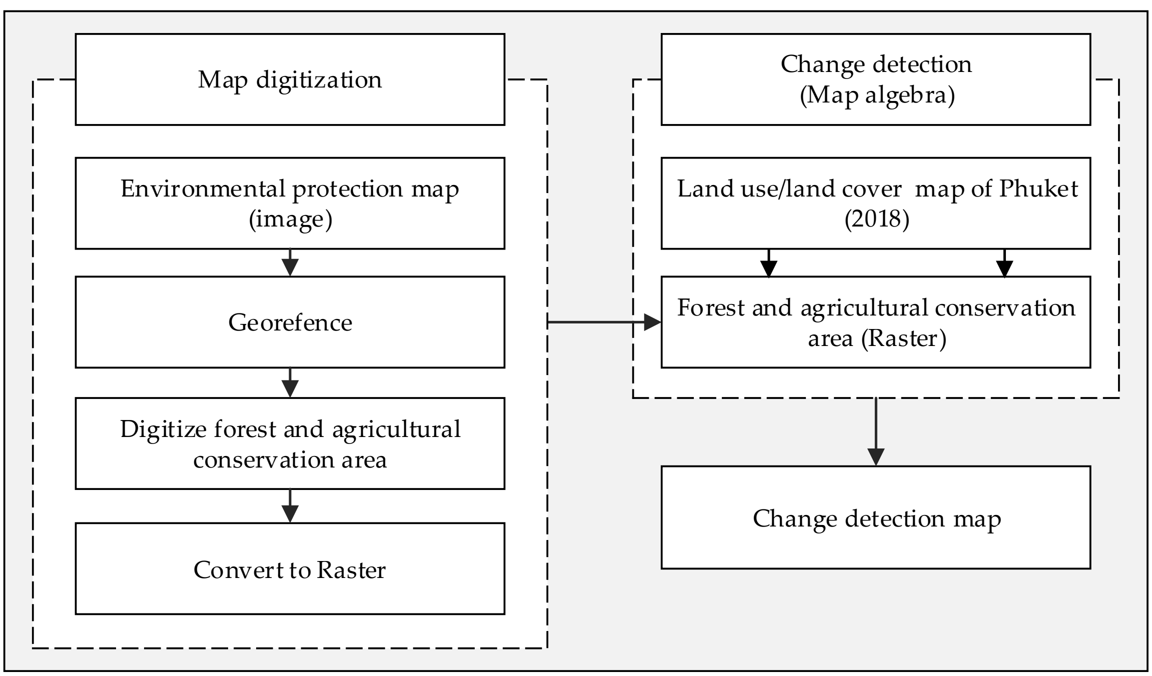


Figure 3.5 The research methodology of land use change in Environmental protection area

3.3.2.2 Land use change in Phuket from 2000 to 2018

Land use map of Phuket in 2018 was integrated with the other five datasets of LDD land use (2000, 2007, 2009, 2013, and 2016) to investigate land-use change in Phuket over 19 year period. Since there were a slight difference of each data characteristic such as different coordinate system, categories of land use, and raster conversion (as shown in Figure 3.6), data preparation was done before processing and analyzing land use change. A detailed description of each processing step in this section was provided below.

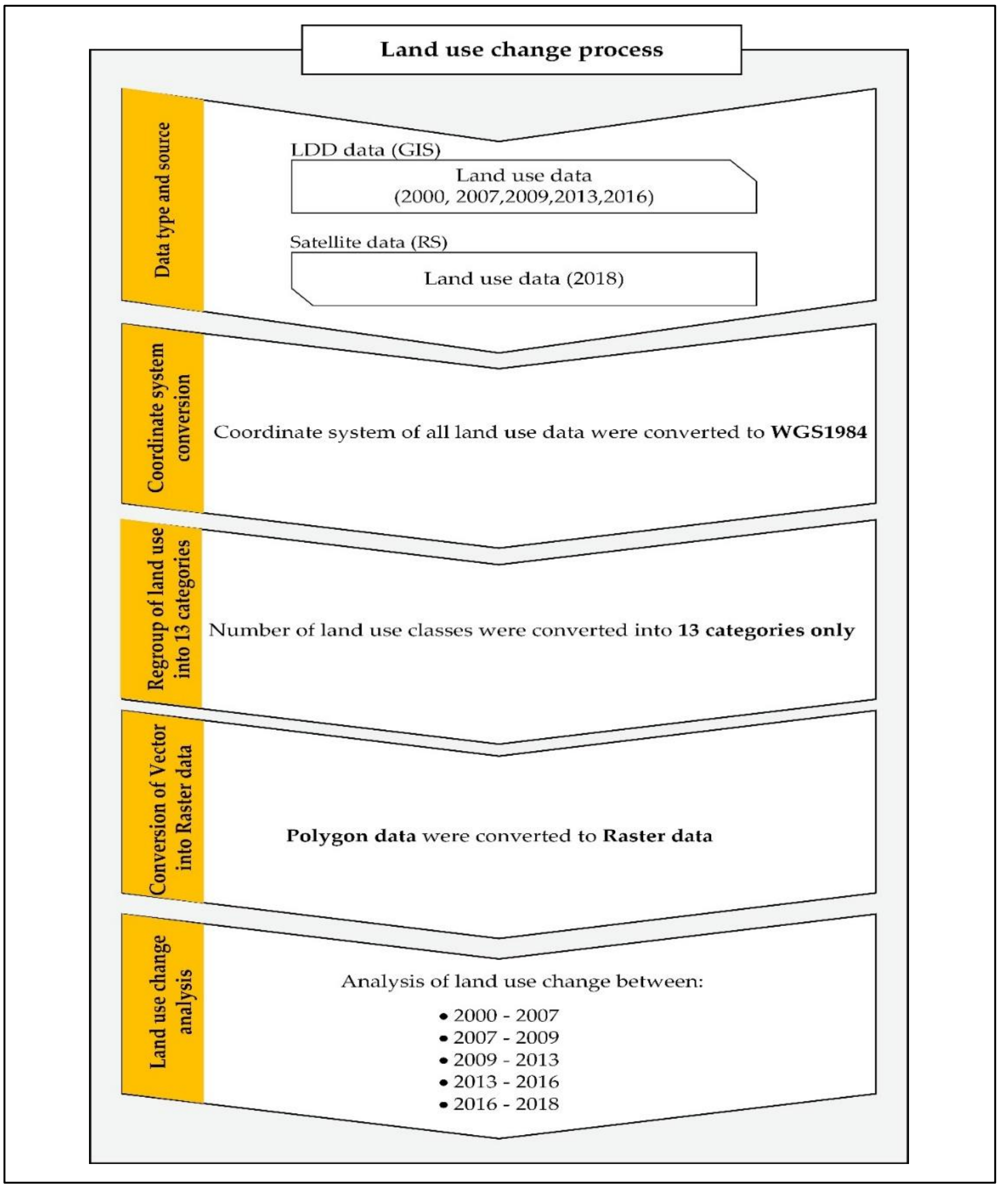


Figure 3.6 The research methodology of land use change in Phuket province.

- Coordinate system conversion

A coordinate system defines a specific location of an object on the earth's surface. For instance, the object A locates in Phuket by using UTM WGS 1984 coordinate system; however, this object will shift to another province if we use the different coordinate system. In this step, all the Phuket land use map datasets use UTM WGS 1984 except land use map in 2000 which uses UTM Indian 1975. Hence, to reduce the error when processing the land use change analysis, data of land use in 2000 was converted to the same geographic coordinate system, UTM WGS 1984, as other land use datasets. To convert the geographical coordinate system of Phuket land use map (2000) from UTM Indian 1975 to UTM WGS 1984, Projection and Transformation tool in ArcGIS was utilized. After finishing this step, all land use map classes were regrouped into 12 categories.

- Regroup of land use categories

Each of Phuket land use datasets (2000, 2007, 2009, 2013, 2016, and 2018) has different number of categories, range from 12 to 85 categories. To observe the changed area as well as to estimate carbon stocks in Phuket Island, all data of Phuket land use (except map of Phuket land use in 2018 which already made of new 12 classes) were regrouped into the same as new 12 groups (as shown in Table A3.1-A3.5 of Appendices). The reasons for regrouping as new 12 groups are based on three main factors: (1) activities related to tourism (e.g., shopping center, forest area, golf course, built-up reservoirs etc.), (2) the majority of land utilization in Phuket, and (3) categories of land use in 2006 IPCC guideline.

The regroup process was done by using the Select By Attribute tool in ArcGIS. This tool needs basic Structured Query Language (SQL) syntax writing to select a specific land use class. The syntax use in this step is: SELECT [*column1*] FROM [*table_name*] WHERE [*condition*]. After a specific land use category is selected, the category assigned to a new group (new column of Attribute table).

- Vector (Polygon) to Raster conversion

Since all of Phuket land use data are stored as Polygon data and in the next step of processing, Land-use change analysis, requires Raster data as input parameter, therefore all data of Phuket land use were converted to Raster data. Polygon to Raster tool in ArcGIS was utilized by choosing a 10 m x 10 m (100 m^2) cell size.

- Land-use change analysis

In order to understand the area of land-use change in Phuket in detail, the Tabulate Area tool in ArcGIS was employed. Tabulate Area calculates the two datasets of Raster layer by overlapping and producing a matrix table of change areas. This matrix table can show all information of each land use type and the area of change from one category of land to the other categories of land.

3.3.3 Estimation of carbon stocks

The Intergovernmental Panel on Climate Change standard guideline 2006 for National Greenhouse Gases inventories, volume 4 (AFOLU), was followed to estimate carbon stocks in Phuket. The methodologies in this guideline provided three tier levels: Tier 1, Tie 2, and Tier 3. Tier 1 is the simple method in which default parameters (emission factors) could be found in the volume. Similar to Tier 1, Tier 2 employs emission factors based on country or regional data from the literature. The advanced method, Tier 3, requires detailed inventories such as field surveys.

Following the generic decision tree for identifying appropriate tier (as shown in Appendices - Figure A3.1), the present study applied Tier 1 and Tier 2 of 2006 IPCC Guideline to estimate carbon stocks (Eq.1) and other pools of carbon stock (Eq.2) with equations:

$$C_{LU} = AGC + BGC + SOIL + DOM \tag{1}$$

Where

C_{LU} : the total carbon stock of land-use

AGC : above ground carbon (t carbon)

BGC : below ground carbon (t carbon)

SOIL : soil (t carbon)

DOM : dead organic matter (t carbon)

$$AGC_i/BGC_i/SOIL_i/DOM_i = A * EF_i \tag{2}$$

Where

$AGC_i/BGC_i/SOIL_i/DOM_i$: above ground carbon/below ground carbon/soil carbon/dead organic matter of a land use category *i* (t carbon)

A : activity data (ha)

EF : emission factor of a land use category *i* (t carbon of A unit)

3.3.4 Assessment of environmental degradation cost

According to the System of Environmental Economic Accounting, environmental costs include depletion, defensive and degradation cost (3D) (Nations et al. 2003). Depletion cost is the value of withdrawing natural resources, consisting of the cost to turn the environment of systems into initial conditions. Degradation cost accounts for the damage values due to devastating effects on humans and the ecosystem from environmental pollutions. Defensive cost represents the essential money spent on activities to minimize the possibly environmental degradation in the present and the future. With the aim of estimating the economic loss resulting from the detrimental influence caused by GHG emissions on humans and ecosystems, focusing on land use change impact, this study estimates the degradation cost resulted from GHG emissions caused by land-use change. The Life Cycle Impact Assessment Method based on Endpoint Modelling 2 (LIME 2) was adapted to assess the degradation cost from this emission source.

It was an estimate based on LIME2, an assessment method originating from Japan to assess degradation costs assuming as the case closest to Asian conditions. In LIME2, the degradation cost was estimated based on the damage to human health, ecosystem, and social assets. For ecosystem, there are two areas that should be considered: biodiversity and primary production. However, the effects of global warming on ecosystem highly depends on special region conditions, and at the present, most of research focus on predicting the impact in specific condition (Itsubo, N. and Inaba, A. 2012), therefore, biodiversity is not included in the categories of global warming as presented in Table 3.2.

Table 3.2 Category endpoints of global warming in LIME 2

Area of protection	Category endpoint		Object of calculation of damage function		Screening		
					(1)	(2)	(3)
Human health	Heat stress	Increase in deaths due to increase in heat stress Decrease in deaths due to relaxation of cold stress	o	Heat stress, cold stress	o	o	Δ
	Infection	Increase in infection suffered through animals	o	Malaria, dengue	o	o	o
			×	Yellow fever, schistosomiasis, etc	Δ	×	Δ
	Air pollution	Worsening of impact tropospheric ozone	×	Poor quantitative information	Δ	Δ	×
	Disaster damage	Weather disasters, such as flood and typhoon	o	Death damage	o	o	Δ
	Malnutrition, Starvation	Change in the food situation due to change in agricultural production	o	Aspect of malnutrition (excluding starvation)	Δ	o	Δ

Table 3.2 Category endpoints of global warming in LIME (Continued)

Area of protection	Category endpoint		Object of calculation of damage function		Screening		
					(1)	(2)	(3)
Social asset	Agri. production	Changes in quantity/quality of farm products	o	Value of agri. Production (limited to 3 main grains)	o	o	o
	Wood production	Changes in growth speed/quality of forests	×	Value of wood production	Δ	o	×
	Fishery production	Impact on fish/aquaculture	×	Poor quantitative information	Δ	o	×
	Energy consumption	Increase in no. of days of cooling, decrease in no. of days of heating	o	Value of energy consumption	o	o	o
	Land loss	Land loss due to submersion caused by sea level rise	o	Value of lost land area	o	o	Δ
	Water resources	Change in amount of available freshwater	×	Poor quantitative information (impact is partially reflected in agri. production)	o	Δ	Δ
	Immigration	Incurrence of immigration cost due to rise in sea level	×	Poor quantitative information	o	Δ	×

Table 3.2 Category endpoints of global warming in LIME 2 (Continued)

Area of protection	Category endpoint		Object of calculation of damage function		Screening		
					(1)	(2)	(3)
Social asset	Assets loss	Loss of social assets due to weather disaster	×	Poor quantitative information	o	×	×
	Impact on insurance	Increase in insurance cos	×	Poor quantitative information	o	×	×
Primary production	Terrestrial ecosystem	Change in production capacity of terrestrial plants	×	Net primary production (NPP) of latent information	o	o	Δ
	Aquatic ecosystem	Change in production capacity of phytoplankton	×	Poor quantitative information	o	o	×
	Land loss	Land loss due to submersion caused by sea level rise	×	NPP corresponding to lost land area	o	o	Δ
Biodiversity	Terrestrial ecosystem	Change in composition of species due to climate change	×	Poor quantitative information	-	-	-
	Aquatic ecosystem	Change in composition of species due to climate change	×	Poor quantitative information	-	-	-

Source: Itsubo, N. and Inaba, A. 2012

Note: Screening criteria

1) The probability of occurrence of damage should be more than about the middle.

2) Damage should be thought to be large according to existing research or public perception.

3) There should be quantitative information for assessment.

o: fulfilling the criteria; Δ: between fulfilment and non-fulfillment; and ×: not fulfilling the criteria.

After considering all damage, the guideline proposes a degradation cost of 2.33 JPY per one kg CO_2-eq. This cost is converted into Thai currency using Eq (3) and Purchasing Power Parities (PPP) that presents the amount of money to buy the same amount of similar goods between two countries. Information for PPP was collected from the World Bank(World Bank 2019a).

$$\text{Degradation cost/kg } CO_2\text{eq (Baht)} = \left[\text{Degradation cost/kg } CO_2\text{eq (JPY)} \times \frac{\text{PPP of Thailand (Baht)}}{\text{PPP of Japan (JPY)}}\right] \tag{3}$$

Then, the total degradation cost caused by global warming is calculated using eq (4), then converted into USD by using official exchange rate from World Bank data (World Bank 2019b). The conversion factor for PPP and exchange rate are presented in Table A3.6 of Appendices.

$$\text{Degradation cost (USD)} = \left[\text{Degradation cost/kg } CO_2\text{eq (baht)} \times \text{quantity of } CO_2\text{eq} \times \text{exchange rate}\right] \tag{4}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Land use/land cover classification

Figure 4.1 depicted a typical map of Phuket land use/land cover (2018) which is produced using Remote Sensing data, Sentinel-2 with the supervised classifier, Random Forest. In 2018, the Settlements area occupied most of the Phuket area, nearly 30% or 162.96 km^2. These areas included all services or other activities related to humans such as airport/harbor, resort/hotel, residential village, etc. After that, the plantation of rubber trees was the second dominant utilization of land. It covered nearly 29% or 157.83 km^2 of the total land. The third occupation of Phuket land in 2018 was forest area, 24% or equal to 130 km^2 which comprised Mangrove forest with ~5%, and Other forest with around ~19% (Evergreen forest and Deciduous forest). These three main categories (Settlements, Rubber tree, and forest) accounted for nearly 85% of the total land utilization in Phuket. Other types of land which accounted for less than 5% of the total land on this island were Golf course, Grassland, Aquaculture area, Reservoir, Other water body (such as a lake, canal, farm pond), Paddy field, Other agricultural area (including other types of crops such as coconut, oil palm, and pineapple), and Other land (such as abandoned land, cemetery, and landfill).

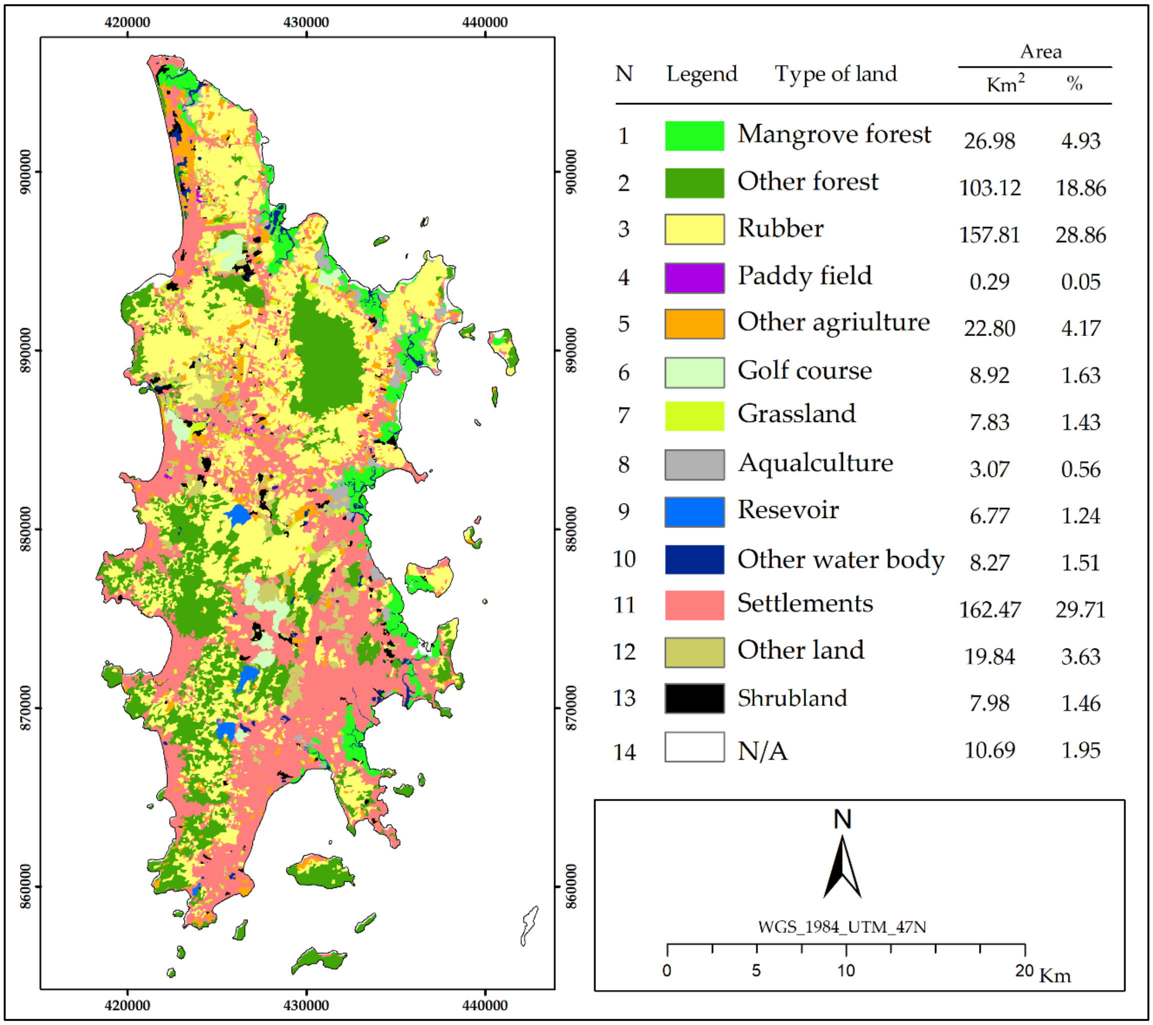


Figure 4.1 Map of Phuket land use/land cover classification in 2018

After performing the completed land use/land cover classification and creating a land use/land cover map of Phuket in 2018, an accuracy assessment was performed to check the quality of the land use/land cover classification result. As mentioned above (in Chapter 3 - Methodology), this study employed 10-fold cross-validation accuracy assessment; therefore, the accuracy validation of Phuket land use/land cover classification was presented as an average of 10-fold in one table (Table 4.1). As shown in Table 4.1 the accuracy assessment of the present study achieved a satisfactory result with average of overall accuracy assessment at 86%, and Kapp coefficient was 82% while the overall accuracy of 85% is the standard representing the cutoff point between acceptable and unacceptable results (Congalton and Green 2008). By observing the results of the confusion matrix of each fold cross-validation (presented in Table A4.1 to A4.10 of Appendices), the accuracy is influenced mainly by the misclassification among three land use categories including Other forest, Rubber plantation, and Other agricultural land. For instance, Rubber plantation was misclassified and assigned as Other forest. It might slightly affect the result of carbon stock which is estimated based on Phuket land use map in 2018. However, this research achieved an acceptable overall accuracy assessment of 86%.

Table 4.1 The average accuracy assessment of 10-fold cross validation

Fold	1	2	3	4	5	6	7	8	9	10	Average
Overall accuracy	89.77	84.09	82.95	84.09	86.36	85.23	86.36	85.23	88.64	87.50	86.02
Kappa accuracy	87.29	80.14	78.80	80.23	83.14	81.69	82.86	81.35	85.97	84.51	82.60

Then, Table 4.2 reveals the result of the comparison between the produced map of Phuket's land use/land cover with a map created by LDD (LDD land use/land cover map in 2018 was released during this last period of this study). The most noticeable differences are the gaps of other forest area (6.86%) and rubber plantation (7.93%) between 2 maps. For other categories, there were minor or no differences as details shown in Table 4.2. In case there are time and budget constraints, the methods presented in this study could be applied to create a new map with acceptable accuracy.

Table 4.2 The difference in areas by land-use types between the produced map and LDD map

Type of land use	Done by this study		Done by LDD		Differences
	Km^2	%	Km^2	%	%
Mangrove forest	26.98	4.93	25.71	4.70	0.23
Other forest	103.12	18.86	140.63	25.72	6.86
Rubber	157.81	28.86	114.45	20.93	7.93
Paddy field	0.29	0.05	0.22	0.04	0.01
Other agriculture	22.80	4.17	30.56	5.59	1.42

Table 4.2 The difference in areas by land-use types between the produced map and LDD map (Continued)

Type of land use	Done by this study		Done by LDD		Differences
	Km^2	%	Km^2	%	%
Golf course	8.92	1.63	8.94	1.63	0.00
Grassland	7.83	1.43	10.81	1.98	0.55
Reservoir	3.07	0.56	2.84	0.52	0.04
Other water body	6.77	1.24	5.96	1.09	0.15
Aquaculture	8.27	1.51	7.51	1.37	0.14
Settlement	162.47	29.71	154.72	28.29	1.42
Other land	19.84	3.63	19.78	3.62	0.01
Shrubland	7.98	1.46	9.08	1.66	0.20
N/A	10.69	1.95	15.63	2.86	0.90

4.2 Land use change

4.2.1 Change detection in the environmental protection area

The Settlement areas layer of Phuket land use/land cover map in 2018 was used to identify the changed areas in the Environmental protection area by overlapping with forest and agricultural conservation zone (one of the zoning areas in the Environmental protection area). This zone covered areas where altitude over 80 m of mean sea level. In addition, no construction is allowed to build in this zone except the public/state building such as telecommunication building and constructions obtaining permissions from the government. Even though this study could not provide which of them have granted permissions of the construction, the results of the assessment would provide basic information to monitor and manage this conservation zone.

After overlapping the Settlement layer with forest and agricultural conversation zone, it was found that there were several constructions (approximately 4 km^2) built in the conservation zone, and a majority of them was placed in Central and Southern part of Phuket (as shown in Figure 4.2). The similar study conducted by Boupun and Wongsai in 2012 also found that forest, rural, and agricultural conservation areas were decreasing by urbanization (Boupun and Wongsai 2012). Because the change detection map of this study greatly relies on the Phuket classification map in 2018 and to ensure the accurate results, field visits were done to verify changed area by recording coordinate system and elevation using Global Position System (GPS) in order to ensure the accurate results. Each verified area was represented as a data point or a location instead of an area.

The number of 124 locations (in a total of 171) at different places were checked. The construction above 80 m was found in 108 locations (labeled as black triangle point in Figure 4.2) and most of them are hotels, restaurants, and resorts (the coordinate system of those locations is presented in Table A4.13 in Appendices). Those buildings were constructed on hills because it can serve tourists to enjoy sightseeing and beautiful scenery of Phuket from the top view. According to the recent reports, few cases of constructions were prohibited by the governor such as the construction of accommodation in the forest conservation (close to Bang Wad reservoir in Kathu district) was ordered to remove in 2019 (Phuket News 2019a), construction of accommodation in the southwestern coast of Phuket at Krathing Cape was ordered to stop for investigation (Phuket News 2019b). Other 16 locations, in the green label, were the exceptional cases for construction such as telecommunication building, pagoda, and state resort (i.e., Airforce Phuket report station, Phuket Air traffic control center, Big Buddha, Khao Rang hill) because these locations belong to the public/state or for serving the public (not the private properties). The other remaining locations labeled in blue were the unreachable or unverified locations because they are the restricted or private area.

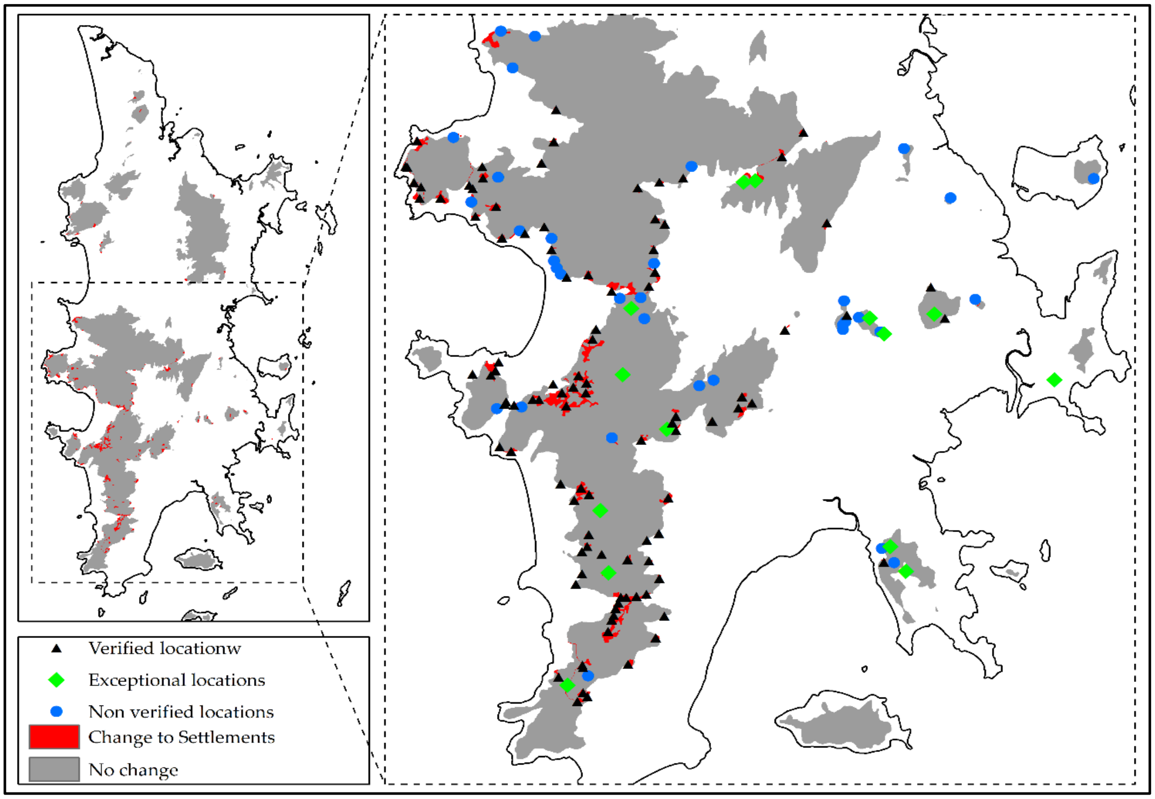


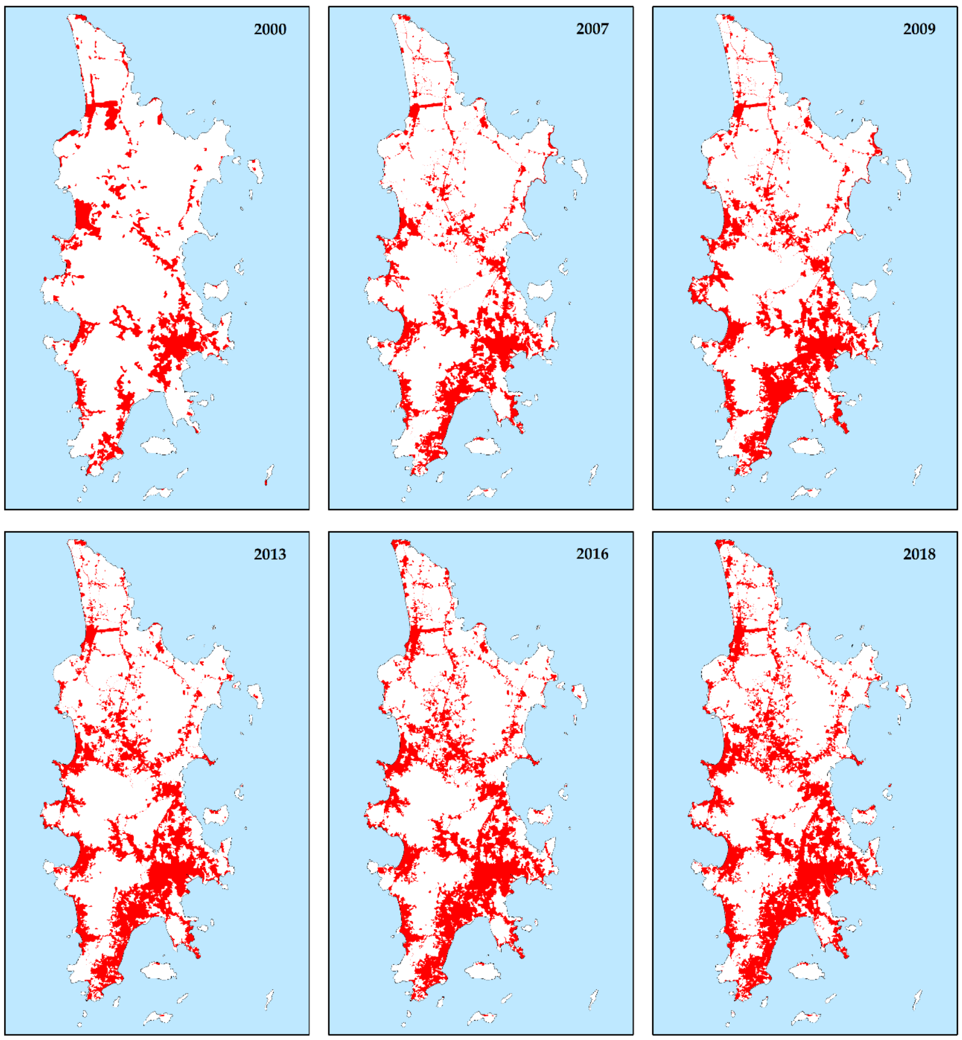
Figure 4.2 The changed area in the environmental protection area.

4.2.2 Land use change in Phuket between 2000 to 2018

(i) Post classification comparison of Phuket land use

In the period of 19 years (from 2000 to 2018), two major shares of Phuket land use were Settlement area (15%-30%) and agricultural area (53%-29%) including para rubber, paddy field, and Other agricultural land (i.e., coconut plantation, oil palm plantation, and pineapple cultivation). After this, the third largest contribution of Phuket land was Mangrove forest and Other forest (evergreen forest and deciduous forest), approximately 17% to 24%). The remaining parts of Phuket land which occupied less than 5% were Golf course, Grassland, Aquaculture area, Reservoir, Other water body (such as lake, canal, and farm pond), and Other land (such as abandoned land, cemetery, and landfill).

As being affected by economic growth, Phuket land use has been altered toward the direction facilitating the development of tourism. Between 2000 and 2018, Settlements areas increased from 82.05 km^2 to 162.96 km^2 (as shown in Figure 4.3). An expansion of Settlements areas about 3% was recorded in every period. Prueksakorn et al. (2017) also mentioned this expansion is the result of the construction of the predominant infrastructures such as restaurants, hotels, and resorts, shopping malls as well as roads in order to facilitate tourists visiting Phuket (Prueksakorn et al. 2017).



Legend	Type of land	Area (km^2) 2000	2007	2009	2013	2016	2018
(red)	Settlement area	82.05	104.60	124.58	140.88	153.87	162.47
(white)	Other types of land (excluded Settlement)						

Figure 4.3 The changed areas of Settlements in Phuket from 2000 to 2018.

Phuket is known as tourism province, ranked second place after Bangkok on number of tourists visiting Thailand (Torres Chavarria & Phakdee-auksorn, 2017). The majority contribution of Phuket GPP (as shown in Figure 4.4) was non-agricultural source which included mainly accommodation and food service activities (the detailed sub-group of non-agricultural GPP are presented in Table A4.12 in Appendices). Considering with these factors, Phuket is not only an attractive island for tourist's holiday, but it could be a favor place of local people for income earing also. Consequently, the areas of Settlement were extended as the demand for serving and earning of tourist and local people.

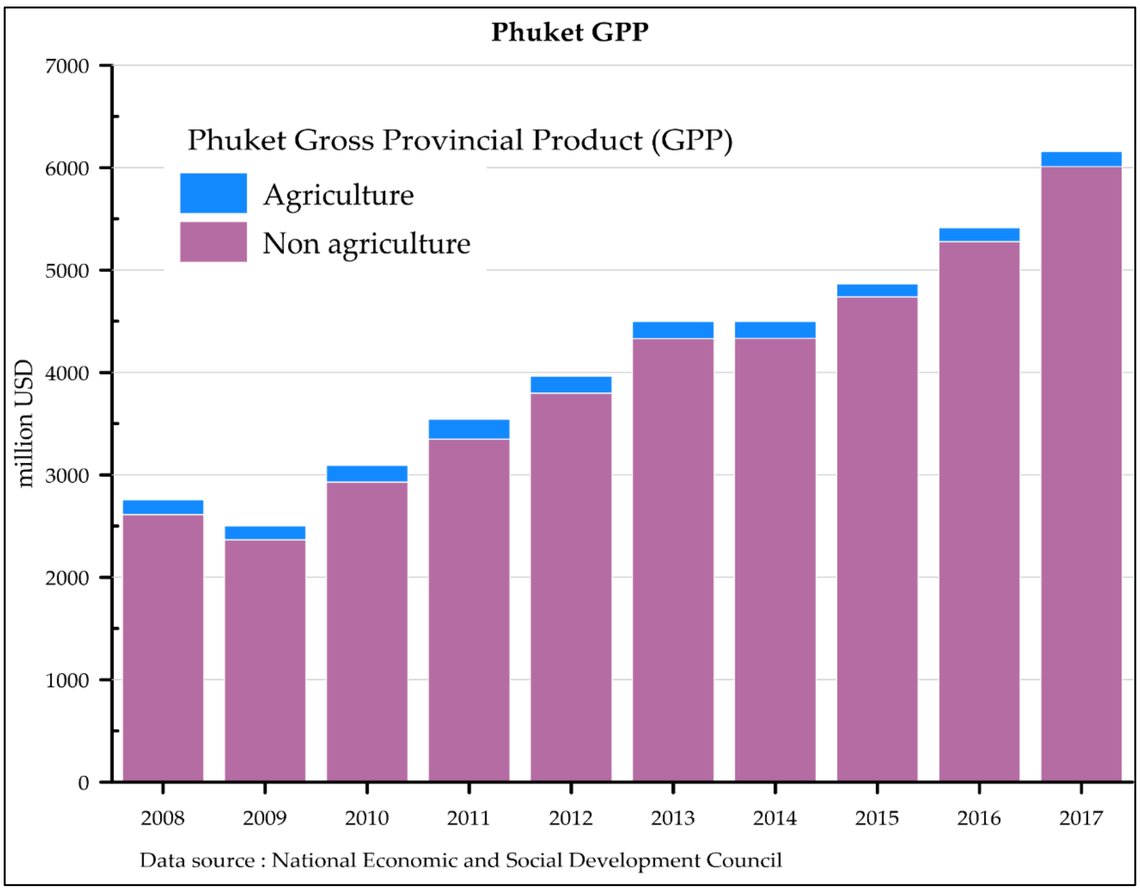
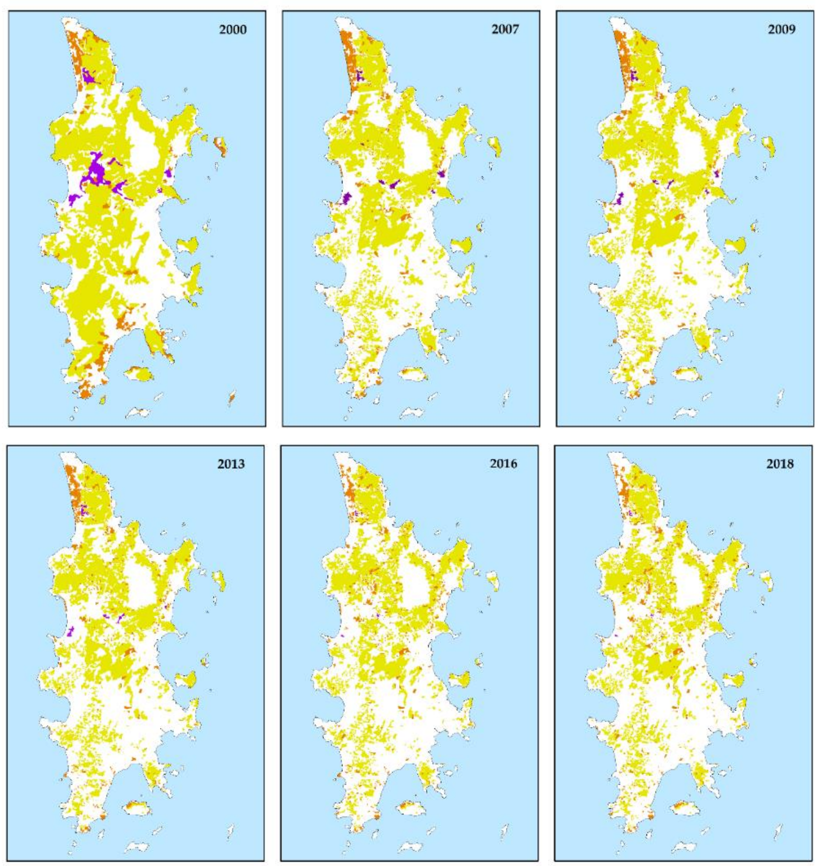


Figure 4.4 The contribution of Phuket GPP between 2008 and 2017

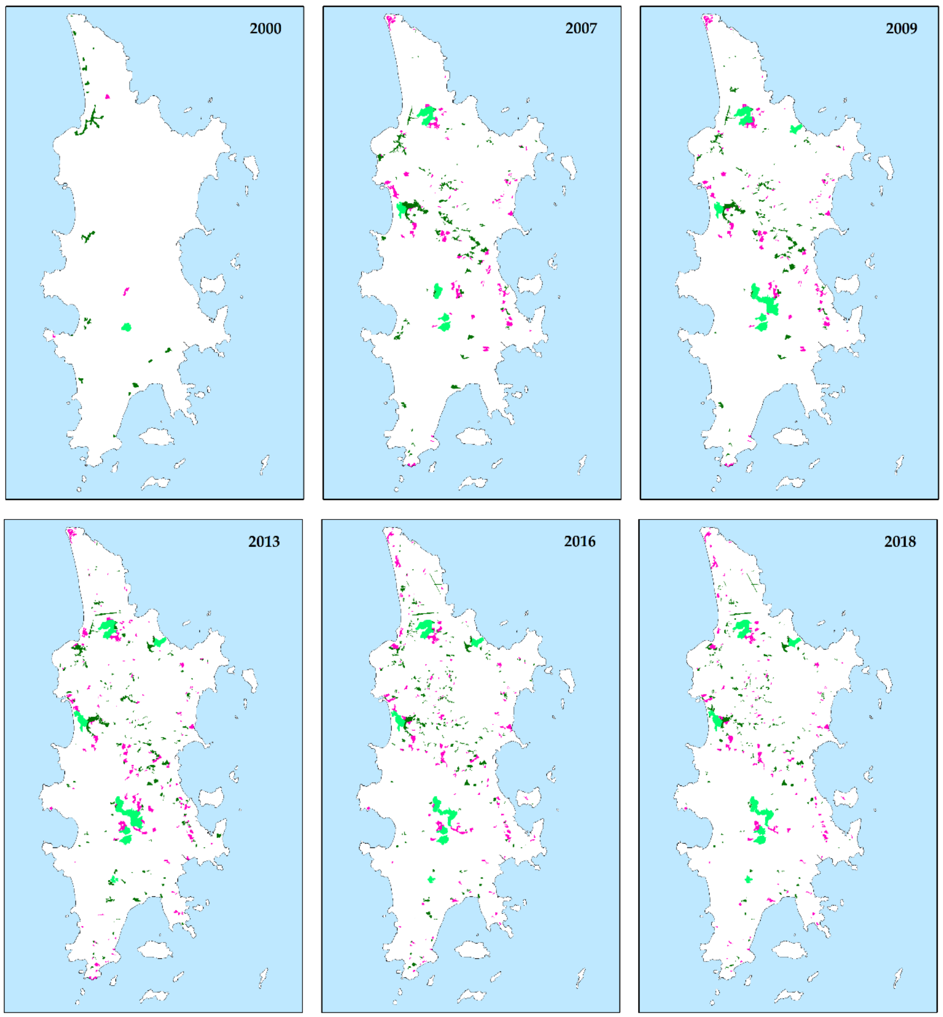
Oppositely, most agricultural land types experienced a remarkable reduction. As shown in Figure 4.5, the area of Rubber has been decreasing about 55 km^2 (from 2000-2007), 4 km^2 (from 2007-2009), 15 km^2 (from 2009-2013), 21 km^2 (from 2013-2016), 4 km^2 (from 2016-2018). In addition, Paddy field also sharply dropped in the first study period (2000-2007) from 12.37 km^2 to 3.27 km^2. This area of land continues to decrease to 0.29 km^2 in 2018. According to a report in 2009, numbers of rice fields in Phuket can provide an adequate supply of rice within the province before the tin mining era and tourism age (Phuket News 2019c). However, recently Phuket needs to import rice from other places. Other agricultural area, it was almost no change since the beginning period (2000) till 2018. In fact, the drop of agricultural area (include Rubber, Paddy field, and Other agriculture) was the reflection of the fourth national economic and social development plan (1977-1981) which aimed to formulate Phuket as tourism province.



Legend	Type of land	Area (km^2)					
		2000	2007	2009	2013	2016	2018
	Rubber	256.66	201.48	197.64	182.24	161.02	157.81
	Paddy field	12.37	3.27	2.36	1.58	0.36	0.29
	Other agricultural	25.91	21.86	20.17	19.36	21.22	22.80
	Other types of land (excluded Rubber, Paddy field & Other agriculture)						

Figure 4.5 The changed areas of agricultural land in Phuket from 2000 to 2018

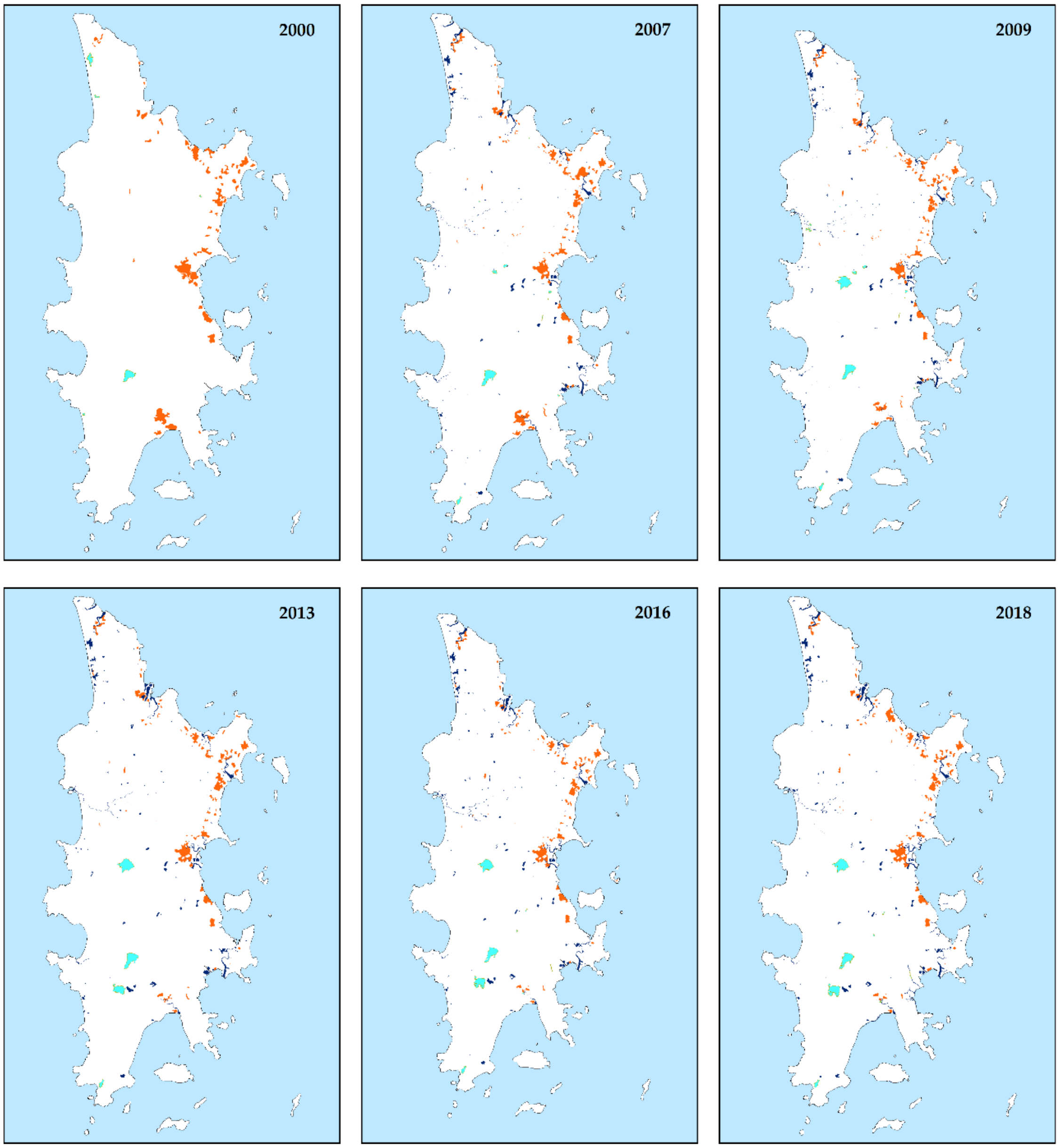
Also, the success of the fourth national economic and social development plan led to the expansion of tourism facilities area such as the bigger Golf course. The area of Golf course in Phuket had been extended ten times in 14 years from 0.72 km^2 in 2000 to 10.05 km^2 in 2013. After 2013 this area was slightly decreased, but it was still eight times larger than years 2000. For the area of Grassland and shrubland, it slightly fluctuated all over the period.



Legend	Type of land	Area (km^2)					
		2000	2007	2009	2013	2016	2018
	Golf course	0.72	5.79	9.42	10.05	8.89	8.92
	Grassland	3.78	9.94	8.43	11.02	10.29	7.83
	Shrubland	0.47	7.69	7.30	9.88	9.68	7.98

Figure 4.6 The changed areas of Golf course, Grassland, Scrubland in Phuket

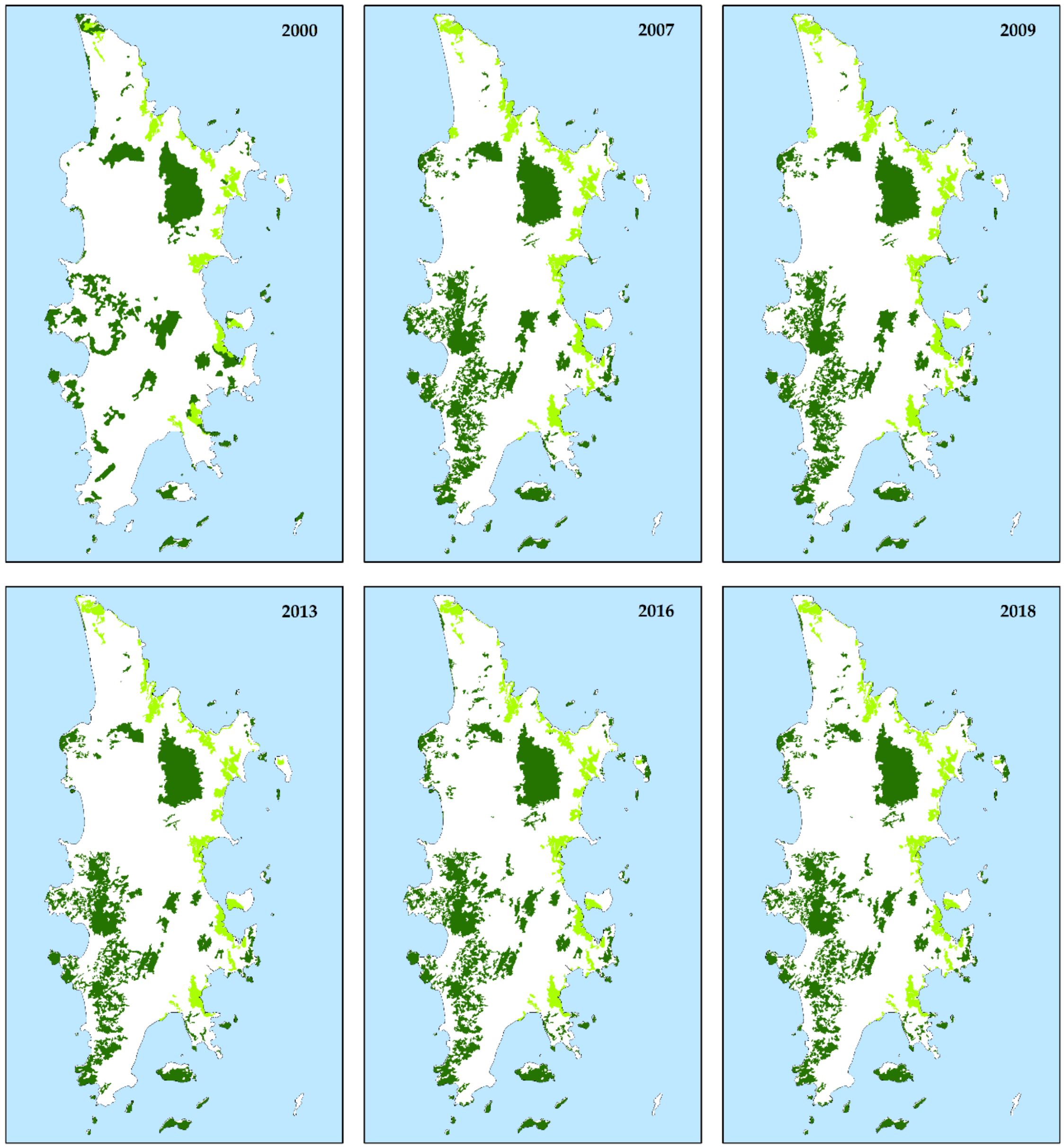
Due to the awareness of high-water consumption in Phuket Island to serve residents and tourism needs, Reservoir and Other water body areas also have been expanded ten times between 2000 and 2018 (as shown in Figure 4.7). This is the result of the construction of new water bodies, for instance, the Bang Neaw Dam reservoir was completely constructed in the year 2006 between period of study 2000-2007 (Phuket Provincial 2018). Furthermore, construction of Klong Katha reservoir (also known as Chalong dam), which serves 10,000 residents, was finished in 2017. This project cost was 480 million Baht (about 150 thousand USD) with a maximum water storage capacity of 4.3 million m^3 (Phuket News 2017). To avoid water shortage in the future, the extension water storage capacity of Bang Neaw Dam reservoir has been proposed and pended for approval (Phuket News 2019d). All these factors indicated that several appropriated planning activities have been implemented in Phuket to serve residents and tourism need.



Legend	Type of land	Area (km²)					
		2000	2007	2009	2013	2016	2018
	Reservoir	1.14	1.44	2.67	2.91	3.07	3.07
	Other water body	00.00	4.94	5.17	5.86	6.13	6.77
	Aqualculture	10.79	9.82	8.79	8.26	7.84	8.27

Figure 4.7 The changed area of Reservoir, Other water, and Aquaculture in Phuket

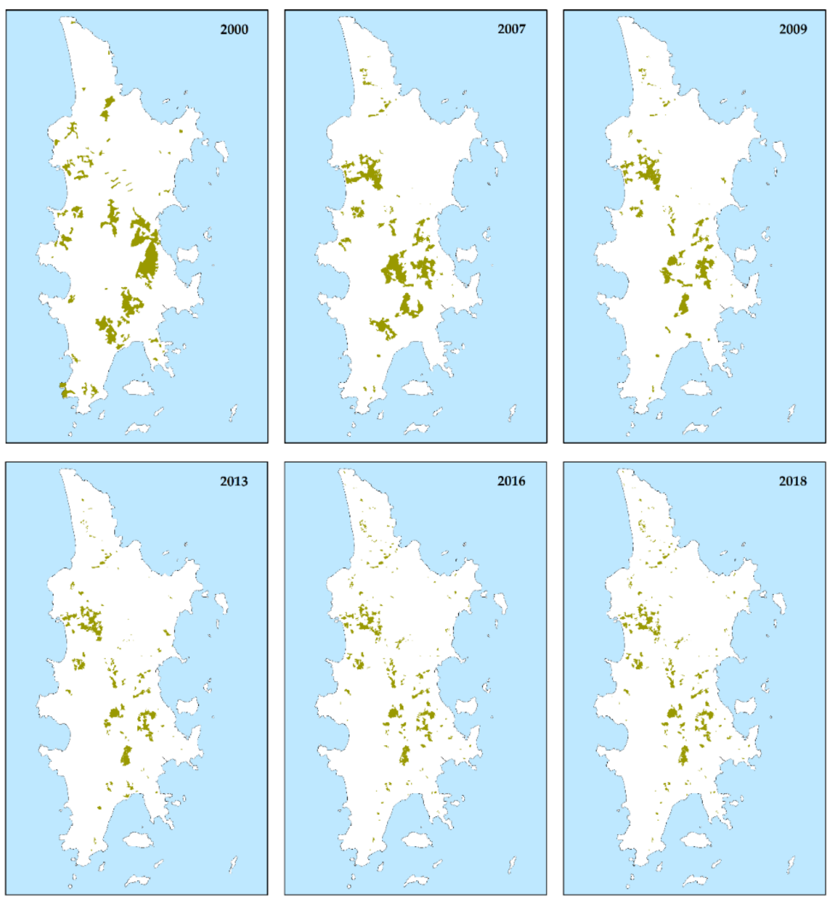
Although the area of forest fluctuated from one period to another period in general, there was an upward trend of forest in the studying period. From 2000 to 2007, the area of Other forest increased by 24 km^2 (Figure 4.8). The reason for its increase during that time because in 1975 Thai government launched a policy, land-reform scheme, to provide the degraded forest area to low-income farmers for crop cultivation only. However, there is a difficulty to access some of those lands because of steep slopes; therefore, the unplanted areas turned to be forest area (Prueksakorn et al. 2017). Between 2007 and 2009, forest area slightly decreased by 4 km^2. However, the announcement of the Ministry of Environment and Natural Resources, in 2010, on environmental protection zoning which covered the manufacturing area, agricultural area, forest area, and territorial water surrounding Phuket Province, resulted in the forest areas increase between 2009 and 2016. In the last period from 2016 to 2018, the forest slightly decreased despite the release of the zoning map of environmental protection in 2017. It might be because during 2016, there was the construction of two remarkable buildings, the extension of the international airport, and central supermarket. Similarly, an increasing trend was recorded in Mangrove forest area. Tookwinas (2004) reported that under the National Mangrove Rehabilitation Project, mangrove forest has been replanted about 5,353 ha from 1997 to 2001 in coastal provinces (32 ha in Phuket province) (Tookwinas 2004). For this reason, it could be a mirror to explain the significant increase of Mangrove forest from 2000 to 2007 and since from that time, this category had almost no change stable till the end of study period, 2018.



Legend	Type of land	Area (km²)					
		2000	2007	2009	2013	2016	2018
	Mangrove forest	19.95	30.80	30.14	28.20	27.80	26.98
	Other forest	77.17	101.18	97.40	96.25	106.15	103.12

Figure 4.8 The changed area of Mangrove and Other forest in Phuket from 2000 to 2018

Other land which included all types of abandoned land such as abandoned aquaculture land, abandoned mining, abandoned paddy, soil pit, cemetery, etc. The area of this land has been decreasing by 7 km^2, 11 km^2, 3 km^2, and 1 km^2 between 2000-2007, 2007-2009, 2009-2013, and 2013-2016, respectively (Figure 4.9). Between 2016 and 2018, the area of Other land remained stable because of the process of Phuket land use/land classification in 2018. The layer of Other land from land use 2016 was applied to mask the area of Phuket 2018. The reason for doing this was the characteristic of Other land was very diverse (i.e., it included abandoned land, soil pit, and cemetery), so to improve the land use/land cover classification this area of land was assumed - no change.



Legend	Type of land	Area (km^2) 2000	2007	2009	2013	2016	2018
	Other land	41.05	34.68	23.65	20.22	19.77	19.84

Figure 4.9 The changed area of Other land in Phuket from 2000 to 2018

(ii) Phuket land use change matrix for 19 years from 2000 to 2018

The area of land use change in Phuket from 2000 to 2018 is shown in Table 4.3. During these 19 years, Phuket has a great change in land use, particularly the area of agriculture and Settlements area. The total area of agriculture (including area of Rubber, Paddy field, and Other type of agriculture) was significantly decreased by about 114 km^2 from 2000 to 2018. Most of the decreased areas, about 62 km^2, were transformed to Settlements (as shown in Table 4.3) and it was the major contribution causing the increase in the area of Settlements from 82.05 km^2 in 2000 to 162.47 km^2 in 2018.

The number of tourists coming to Phuket has been increasing after the national economic development plan revealed. For instance, the number of tourists coming to Phuket was 3 million in 2000, 6 million in 2005, 9 million in 2010, and 12 million in 2015. Therefore, to welcome more tourists, some parts of agricultural land has been also replaced by tourism facility such as Golf course. From 2000 to 2018, the area of Rubber plantation, approximately 4 km^2, was converted as Golf course (as shown in Table 4.3), causing the area of Golf course expanded by 8 times from 0.72 km^2 in 2000 to 8.92 km^2 in 2018.

The rapid growth of tourists accompanied by a significant increase in people residing on the island has led the rose of water consumption. To solve this problem, the area of water (included Reservoir and Other water) has been expanded from 1.14 km^2 to 9.84 km^2 to ensure there is enough water supply for tourists and residents. The increasing areas were mainly from forest area and agricultural area. For the forest area, even though there were a fluctuated trend of change between each period, it generally increased from 19.95 km^2 to 26.98 km^2 for Mangrove forest, and from 77.17 km^2 to 103.12 km^2 for Other forest area between 2000 to 2018. As shown in Table 4.3, the change mostly came from the agricultural area. This is in line with another study mentioned the reason of increasing forest area - agricultural land provided by government turn as forest because those provided land were difficult to access or plant. For the other transitions of land use change in periods, 2000-2007, 2007-2009, 2009-2013, 2013-2016, and 2016-2018 are also presented in Table A4.14 to A4.18 and in Figure A4.2 to A4.4 of Appendices.

Table 4.3 Land use change matrix of Phuket between 2000 and 2018

Type of land use		Land use (2018)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Land use (2000)	1	14.84	0.02	0.41	0.00	0.32	0.00	0.05	1.17	0.01	1.20	0.90	0.12	0.11	0.82	19.95
	2	3.17	47.01	13.32	0.00	1.00	0.11	0.37	0.42	0.15	0.08	7.48	0.81	0.52	2.72	77.17
	3	2.11	47.31	131.06	0.01	11.00	4.41	2.91	0.41	1.69	1.33	44.29	5.17	3.16	1.82	256.66
	4	0.01	0.06	1.32	0.22	1.10	0.00	1.52	0.18	0.00	0.03	5.08	2.75	0.10	0.00	12.37
	5	0.62	1.59	3.16	0.00	4.50	0.00	0.36	0.27	0.01	0.33	13.06	0.26	0.62	1.11	25.91
	6	0.00	0.03	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.72
	7	0.01	0.14	0.29	0.00	0.27	0.01	0.27	0.22	0.00	0.00	1.99	0.19	0.37	0.03	3.78
	8*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00
	9	0.00	0.19	0.11	0.00	0.03	0.00	0.01	0.25	0.39	0.00	0.06	0.00	0.11	0.00	1.14
	10	1.68	0.03	0.79	0.00	0.52	0.03	0.06	0.24	0.01	4.20	2.35	0.34	0.11	0.42	10.79
	11	0.84	2.05	3.76	0.06	2.12	3.32	1.00	0.72	0.29	0.47	62.35	1.82	1.32	1.93	82.05
	12	0.43	2.34	3.33	0.00	1.72	0.36	1.26	0.81	0.53	0.24	20.15	8.14	1.52	0.22	41.05
	13	0.00	0.08	0.07	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.04	0.22	0.00	0.00	0.47
	14	3.26	2.27	0.19	0.00	0.18	0.00	0.01	2.10	0.00	0.38	4.72	0.01	0.03	1.62	14.78
Total		26.98	103.12	157.81	0.29	22.80	8.92	7.83	6.77	3.07	8.27	162.47	19.84	7.98	10.69	546.83

* In 2000, the land use type of Other water body is not available

1. Mangrove
2. Other forest
3. Rubber
4. Paddy field
5. Other agricultural area
6. Golf course
7. Grassland
8. Other water body
9. Reservoir
10. Aquaculture
11. Settlements
12. Other land
13. Shrubland
14. N/A

4.3 Estimation of carbon stock and CO_2 emission from land use change

The appropriate Tier method in this study was Tier 1 due to the limitation of available data. The country-specific data (emission factor) or Tier 2 are not available for each category of land use while Tier 3 is an advanced method requires more resources (i.e. budget and time). Therefore, most of the emission factor were the default value or global data. It should be noted that Tier 1 of IPCC assumed that dead organic matter (DOM) of other land use types is zero for all land use types except Forest land (IPCC 2006; Thapat and Jintana 2015).

Even though Tier 1 was applied to calculate the carbon stock in Phuket Island, the conditions to apply emission factors such as species, climate, and elevation were also checked before usage. For instance, a survey showed that *Zoysia metrella* of turfgrass is used for Golf course in Thailand (ASIAN Turfgrass Center 2011). Therefore, the emission factor of this species was utilized even its study in Hong Kong (Kong et al. 2014). According to IPCC guideline 2006, Shrubland could consider a single category of Grassland (IPCC 2006). Hence, the carbon stock of Shrubland and Grassland were calculated using the same emission factor. The study of para rubber and coconut carbon stock in the coastal region of Thailand were applied for the category of Rubber and Other agricultural area. For forest, the emission factor from Thai-Glob; one of the main organizations which are responsible for Greenhouse gas inventory in Thailand was applied. The carbon stock in each pool is presented in the following table.

Table 4.4 Carbon stocks for different land use types (t carbon/ha)

No	Land use categories	AGC	BGC	Soil	DOM	Total carbon stock
1	Mangrove forest	82.6[a]	38.8[a]	122.1[f]	51.7[a]	295.29
2	Other forest	112.5[b]	32.7[b]	238[b]	43.4[g]	426.6
3	Paddy field	3[g]	2[g]	10[g]		15
4	Rubber tree	89.61[c]	26.88[c]	66[g]		182.49
5	Other agricultural area*	50.29[c]	15.08[c]	44.17[h]	**	109.551
6	Golf course	1.2[d]	0.05[d]	30.4[d]		31.65
7	Grassland & Shrublands	2.94[e]	0.72[e]	66.3[e]		69.96

* The emission factor of coconut tree was applied because it has more than 50% of land coverage among Other agricultural area.
** Based on the IPCC Tier 1 assumption, carbon stocks in DOM in all non-forest land-use categories are zero.
Source: [a](THAI-GLOB 2011); [b](Department of Forest Management 2011)
[c] (Gnanavelrajah et al. 2008); [d](Kong et al. 2014)
[e](Mekong River Commission 2017); [f](Ranasinghe and Thimothias 2012)
[g](IPCC 2006); [h](Ranasinghe and Thimothias 2012)

From 2000-2007, under the exertion of government to preserve the forest, the growth in forest area resulted in a small increase in total carbon stock with 0.39 t C. From 2004-2016, there was a growth in the number of tourists in Phuket (except 2009 which was world economic crisis), approximately from 4 million tourists to 12 million (as shown in Figure 4.10). In response, more infrastructure serving tourism was constructed. This might be the cause of the decrease of 1-2 % every period in agricultural land, particularly Rubber plantation after 2007. In contract, the Settlement area kept increasing 2-3 % each period. As a result, carbon stock reduced by 0.83 t C from 2007-2018.

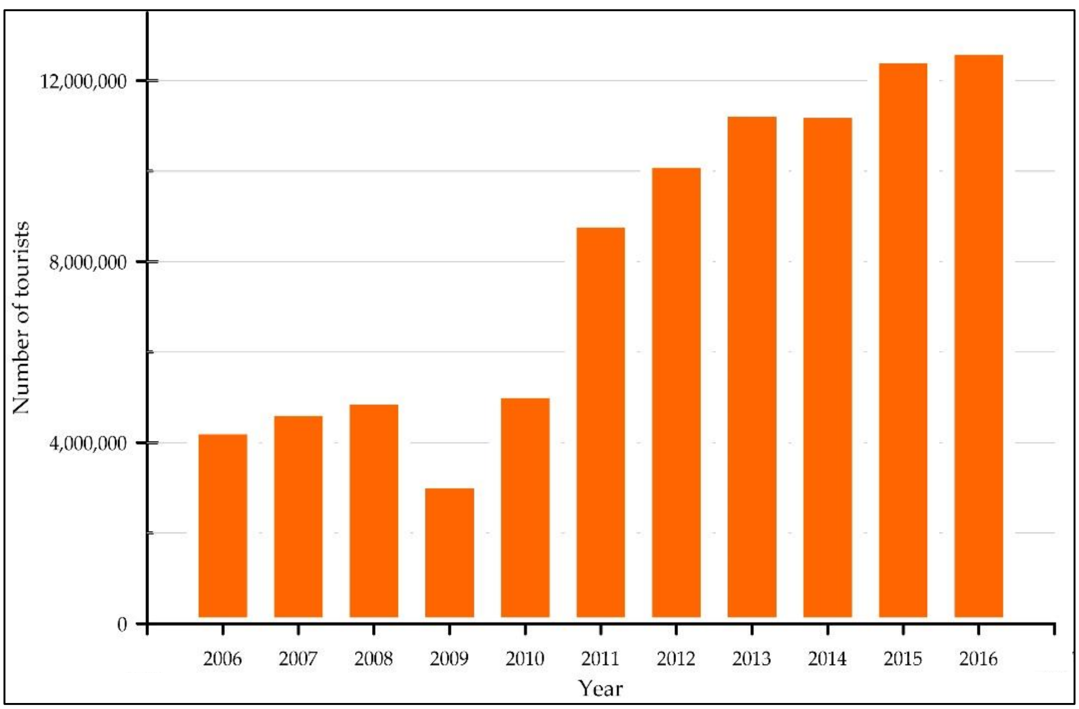


Figure 4.10 The number of tourists visiting Phuket between 2006 and 2016

In general, during 19 years, the major land transformation that affects strongly the main storage of carbon was the changes in Other agricultural area to urbanized land. The replacement of rubber plantation by Settlements areas (approximately 33 km^2) led to the loss of carbon stock. However, since the government has implemented some policies and activities to expand the forest area and regulate the land-use change, the forest area increased by 81 km^2. It helped to mitigate the loss of carbon storage. Therefore, the total carbon stocks slightly declined from 8.90 x 10^6 t carbon in 2000 to 8.46 x 10^6 t carbon in 2018. (Figure 4.11).

Although there was a high rate of land transformation from the main storage of carbon-Other agricultural area to urbanized land, the total carbon stocks were just slightly declined from 8.90 x 10^6 t carbon in 2000 to 8.46 x 10^6 in 2018 (Figure 4.11). This had led to 1.61 x 10^6 t CO_2 eq released into the atmosphere during this period. Despite a huge alteration from agricultural land to urban area, the emission of CO_2 in Phuket was removed by land use change about 1.43 x 10^6 t CO_2 eq from the atmosphere in the period 2000-2007, because there was a growth of carbon gain from the increase in the forest area. Obviously, it was also a consequence of Land-reform policy in 1975 and the cancellation of Mangrove forest land concession in 1996 by Thai government. Between 2007 and 2009, the carbon storage decreased from 9.29 x 10^6 to 9.02 x 10^6 t carbon (equal to 0.99 x 10^6 t CO_2 eq emission) since the area of agricultural area and forest area changed into urban area which led to the loss of carbon storage. This might be the consequence of the implementation of the Sustainable Development of Phuket Tourism Competitiveness 2007 - 2011 development plan which aimed to develop Phuket as premium tropical beach and resort. As a remarkable loss in carbon storage, the CO_2 emissions also grew from 0.99 x 10^6 t CO_2 eq in 2009 to 1.32 x 10^6 t CO_2 eq in 2013. From 2013 to 2016, the agricultural area kept dropping but Other forest rose slightly due to the enactment of the legislation by the Ministry of Natural Resources and the environment in 2010 for the environmental zone in Phuket province (Ministry of Natural Resources and the environment 2010). This resulted in carbon stock increased from 8.66 x 10^6 in 2013 to 8.69 x 10^6 t CO_2 eq in 2016, as well as a removal of CO_2 0.12 x 10^6 t CO_2 eq. For the last period of the study (2016-2018), there still was an alteration of land use towards building accommodation and other facilities for tourists. For instance, the extension of Central Phuket supermarket construction has started in 2016 (Phuket Real Estate 2018), and illegal building have been found in protected area (Phuket News 2019a). Consequently, agricultural area and other forest slightly decreased, causing a carbon stock loss of 0.23 x 10^6 t carbon in this period. Corresponding with the reduce of carbon stock in this period, there was an emission of 0.84 x 10^6 t CO_2 eq in CO_2 emissions.

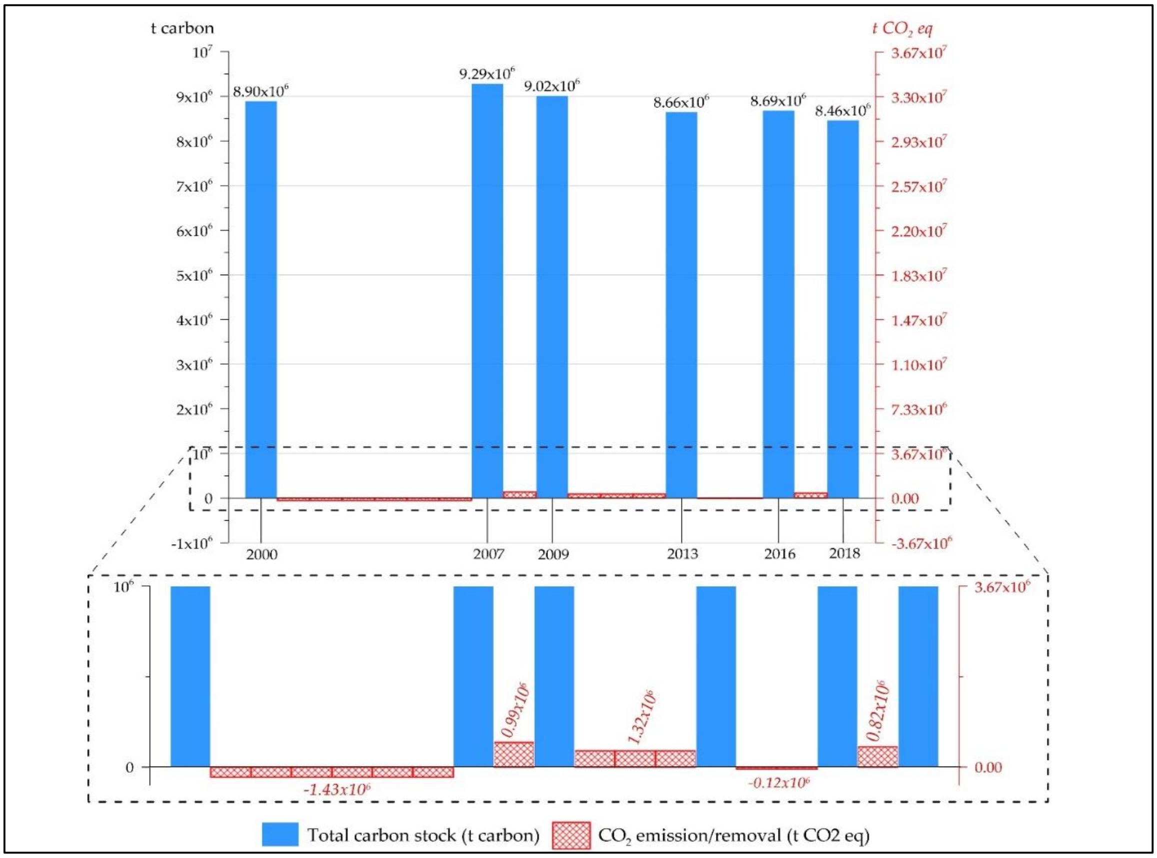


Figure 4.11 The total carbon stocks and CO_2 emission from land use change in Phuket

4.4 Environmental degradation cost from land use change

The results of environmental degradation cost from land use change in Phuket over 19 years are shown in Figure 4.12. From 2000 and 2007, Phuket can remove

1.43 x 10^6 t CO_2 because its increase of forest area. This amount of CO_2 removal helped Phuket save 8.34 million USD for seven years (or 1.19 million USD per year). In addition, Phuket land use is also able to remove CO_2 from the atmosphere in another period of study (from 2013 to 2016) because Other forest, one of the major carbon storages in this island, was increased about 10 km^2 from 96.25 km^2 to 106.15 km^2. Despite the gain of environmental degradation costs between 2000 and 2007, 2013 and 2016, the cost of environmental degradation cost was lost about 13 million USD from 2007-2013 and about 4 million USD from 2016 to 2018. The reason was a decline in both Other agricultural area and Other forest, causing higher emission of CO_2, the higher economic cost of environmental degradation. Although the cost of environmental degradation caused by land use change was less than 1% compare with Phuket GPP between 2008 and 2013, and 2017, the land use still needs to be monitored and adjusted appropriately since it influences to the carbon stock ability-one of the important factor that helps to mitigate climate change.

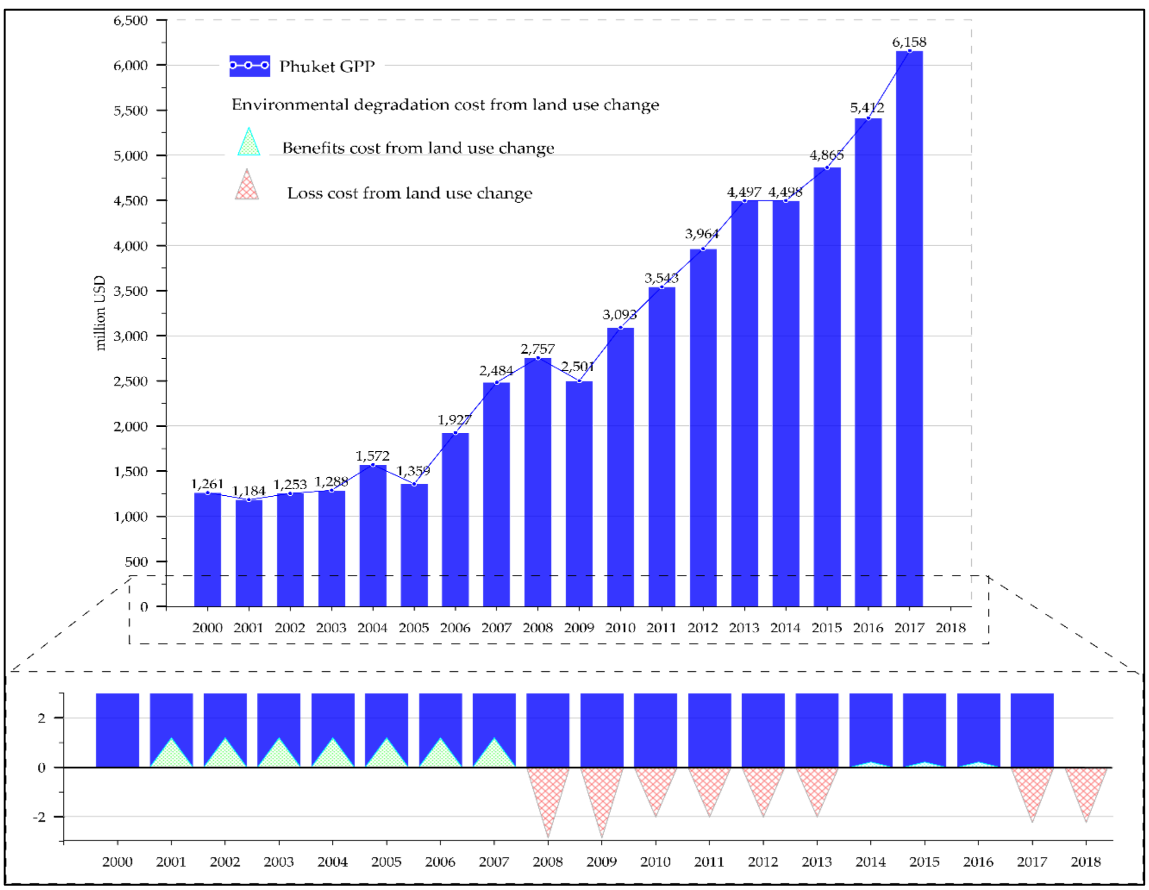


Figure 4.12 The environmental degradation cost of CO_2 emissions from land use change.

4.5 Comparison of GHGs from land use with other sectors

As shown in Table 4.5, there was an increase of approximately 1 million t CO_2eq in the aggregate Phuket GHG emissions from 2012 to 2016. On average, electricity usage occupied the largest share of Phuket's total GHG emissions with almost half of the total carbon footprint. Business and industry were the keenest consumers, making up more than 70% of the total electricity use. Fuel consumption was the second largest contributor to Phuket's total GHGs with a constantly growth t CO_2eq during this time. Following it, waste disposal was the third most significant component of Phuket's total GHG emissions.

In 2012 and 2013, GHGs caused by land-use changes accounted for 13.3 and 5.15% of the aggregate GHG emission in Phuket, respectively. After that, since the forest area increased, the amount of GHG emissions caused by land-use changes reduced by 2.34%, 1.47%, and 0.7%, in 2014, 2015, and 2016, accordingly. Although land use was not an influential factor in the total GHG emissions in Phuket, it should be taken into consideration seriously as an important factor to help reduce GHGs by carbon storage pools and the considerable effects on the ecosystem.

Table 4.5 GHG emissions by sources in Phuket from 2012-2016 (t CO_2eq)

Sectors	2012	2013	2014	2015	2016
Electricity use	951,427	1,446,868	1,357,994	1,452,008	1,562,014
Fuel consumption	751,116	811,422	846,218	910,434	932,084
Rice cultivation	88	87	79	87	85
Other agricultural crops	15,982	15,941	14,607	14,329	14,262
Livestock	5,619	5,176	9,173	6,235	6,119
Waste disposal	257,997	279,913	265,351	278,601	304,625
Land use/cover change	263,857	131,929	-58,584	-39,056	-19,528
Total					
Including LULC	1,982,229	2,559,407	2,493,422	2,661,694	2,819,189
Excluding LULC	2,246,086	2,691,336	2,434,838	2,622,638	2,799,661

CHAPTER 5

CONCLUSION

In this study, Remote sensing, GIS, 2006 IPCC Guideline were applied to examine the land use change and its effect on the changes of carbon stock, and LIME 2 was employed to estimate the cost of environmental degradation in Phuket province from 2000 to 2018. There were significant changes in the three dominant categories of land use: agricultural area (including rubber tree, paddy field, and other types of agriculture), Other forest, and Settlements, in all periods. These changes were related to the national economic and social development plan, as well as the environmental development strategy. Rubber and Paddy field area always decreased in every period, 2000-2007, 2007-2009, 2009-2013, 2013-2016, and 2016-2018. In addition, the results also prove the effectiveness of law enforcement and green area secure such as the increase in Other forest as a result of prohibiting construction in the conservation zone.

There was a fluctuation in the downward trend in the carbon stock during the studying period. This fluctuation was the result of the structural change in land use of forest area and agricultural area into the hotel, restaurant, accommodation, and other construction for serving tourists. Furthermore, a great effort of the government leads to the stability of forest areas or small fluctuation. Despite a slight loss of carbon stock over 19 years, land use still need to be considered seriously since it affects not only carbon storage - one of the main factor in climate change mitigation route, it also has a huge influence in economic development as land use is the first condition of infrastructure development for tourism industry and local people's life. In addition, the cost of environmental degradation loss about 1% from land use change, in this study, it costed slightly over 9 million USD, over half for the construction cost Klong Katha reservoir or Chalong dam, which serves 10,000 residents, (around 15 million USD or 480 million Baht) (Phuket News 2017).

There are also some limitations to this study. The assessment of carbon stocks from land-use change greatly depends on the accurate classification of land use data, and reliable emission factor of carbon stock in different land-use types. However, this research tried to minimize the effects of these factors on the results. In this research, dataset of Phuket land use in 2000, 2007, 2009, 2013, and 2016 were obtained from LDD, a confidential governmental organization. LDD was established in 1963, its expertise in land management includes studying, surveying, analyzing and classifying soil for policy formulation and land use planning; preparing the land census; developing base map system for planning agricultural infrastructure and others. Phuket land use map in 2018 was verified carefully by observing in all three districts in Phuket and ground truth data were collected nearly 1,000 samples with field visits more than 8 times. Also, reliable emission factors of carbon stock were carefully selected by checking rainfall conditions, temperature conditions, and species as well. Whereas these criteria were not found, only emission factors in Asian countries were applied for carbon stock calculation. For environmental protection map, since there was no accessible information on permitted license of building construction in the forest and agricultural conservation zone of the environmental protection area, this study could not provide further information on which construction is not allowed. The results of this work would not provide perfect value, but it provides fundamental information to illustrate the trend of land use change and carbon stocks in Phuket, including environmental degradation cost for policymakers.

The extensive work in the future should be the improvement of the process that can create a map with higher accuracy, as well as the calculation of GHGs emission in all sectors of the 2006 IPCC Guideline, Energy, Industrial Processes and Product Use, Agriculture, and Waste. Thus, the total GHGs emission and environmental degradation cost could be seen as the whole picture.

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APPENDICES

(i) Generic decision tree of IPCC guideline

Before 2006 IPCC guideline was applied to estimate carbon stock in Phuket, the generic decision tree was used to identify appropriate tier method:

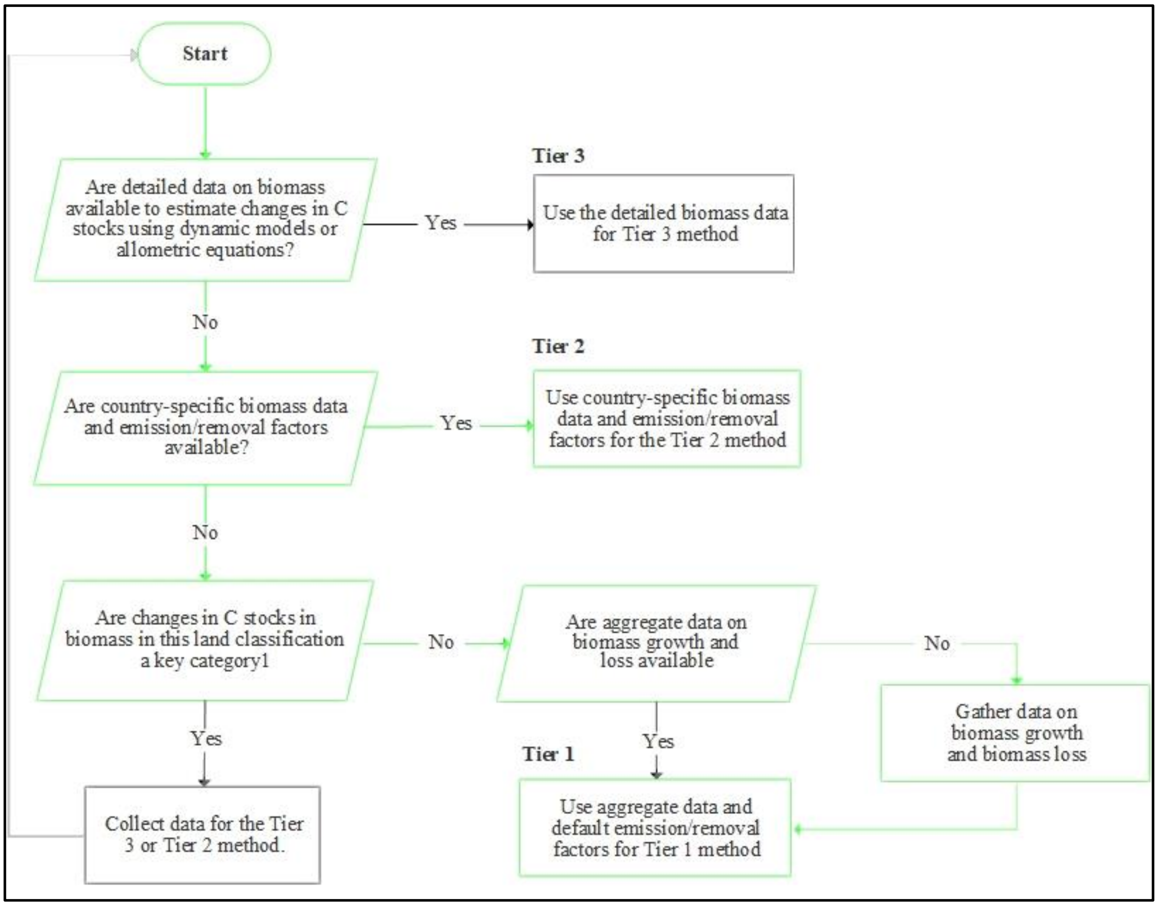

Figure A3.1 Generic decision tree for identify appropriate tier method

(ii) Regroup matrix

Each dataset of land use from LDD contains a wide range of classes. In this study of land use change, they were regrouped as 12 main groups. Each group of land use comprised with several classes as presented in following table.

Table A3.1 The regroup matrix of land use in 2000

Regroup code	Regroup name	Land use categories (2000)	Area		
			Km^2	%	
1	Mangrove		19.96	3.65	
		Mangrove forest	19.96		3.65
2	Other forest		77.16	14.11	
		Beach forest	2.23		0.41
		Disturbed evergreen forest	4.72		0.86
		Moist evergreen forest	70.22		12.84
3	Rubber tree		256.66	46.94	
		Para rubber	208.67		38.16
		Para rubber/Moist evergreen forest	1.58		0.29
		Para rubber-Moist evergreen forest	46.41		8.49
4	Paddy field		12.37	2.26	
		Transplanted paddy field	12.37		2.26
5	Other agricultural land		25.91	4.74	
		Coconut	18.68		3.42
		Coconut/Low land village	0.53		0.10
		Coconut-Low land village	2.03		0.37
		Coconut-Mixed orchard	1.91		0.35
		Coconut-Para rubber	2.47		0.45
		Mixed orchard	0.03		0.01
		Teak	0.18		0.03

Table A3.1 The regroup matrix of land use in 2000 (Continued)

Regroup code	Regroup name	Land use categories (2000)	Area		
			Km²	%	
5	Other agricultural land		25.91	4.74	
		Truck crop	0.09		0.02
6	Golf course		0.72	0.13	
		Golf course	0.72		0.13
7	Grassland		3.78	0.69	
		Pasture and farm house	0.03		0.01
		Wetland	3.75		0.69
9	Reservoir		1.14	0.21	
		Reservoir	1.14		0.21
10	Aqualculture		10.79	1.97	
		Shrimp farm	10.79		1.97
11	Settlements		82.03	15.00	
		Airport	2.44		0.45
		Beach	1.96		0.36
		City, Town, Commercial and Service	30.06		5.50
		Factory	0.51		0.09
		Harbour	0.50		0.09
		Institutional land	2.77		0.51
		Low land village	17.93		3.28
		Low land village/Coconut	2.35		0.43
		Low land village/Mixed orchard	5.11		0.93
		Low land village-Mixed orchard	8.78		1.61
		Recreation area	2.53		0.46
		Recreation area/Golf course	7.09		1.30

Table A3.1 The regroup matrix of land use in 2000 (Continued)

Regroup code	Regroup name	Land use categories (2000)	Area		
			Km^2	%	
12	Other land		41.05	7.51	
		Abandoned aquacultural land	0.06		0.01
		Abandoned mine	32.45		5.94
		Abandoned paddy	6.08		1.11
		Abandoned paddy-Transplanted paddy field	0.49		0.09
		Allocated land project	0.60		0.11
		Soil pit	1.37		0.25
13	Scrubland		0.47	0.09	
		Scrub, Grass and scrub	0.47		0.09
14	N/A		14.78	2.70	
			14.78		2.70
Total			546.83	100	

Table A3.2 The regroup matrix of land use in 2007

Regroup code	Regroup name	Land use categories (2007)	Area		
			Km^2	%	
1	Mangrove		30.80	5.63	
		Dense mangrove forest	29.33		5.36
		Disturbed mangrove forest	1.47		0.27
2	Other forest		101.16	18.50	
		Dense deciduous forest	5.24		0.96
		Dense evergreen forest	95.92		17.54
3	Rubber tree		201.49	36.85	
		Para rubber	201.49		36.85
4	Paddy field		3.27	0.60	

Table A3.2 The regroup matrix of land use in 2007 (Continued)

Regroup code	Regroup name	Land use categories (2007)	Area		
			Km^2	%	
5	Other agricultural land		21.85	4.00	
		Casuarina	0.09		0.02
		Coconut	18.23		3.33
		Durian	0.12		0.02
		Mixed orchard	0.44		0.08
		Mixed orchard/Coconut	0.06		0.01
		Mixed perennial	0.20		0.04
		Oil palm	2.35		0.43
		Truck crop	0.37		0.07
6	Golf course		5.79	1.06	
		Golf course	5.79		1.06
7	Grassland		9.93	1.82	
		Grass	9.13		1.67
		Marsh and Swamp	0.80		0.15
8	Other water body		4.95	0.90	
		Farm pond	0.89		0.16
		Lake	1.59		0.29
		River, Canal	2.47		0.45
9	Reservoir		1.44	0.26	
		Reservoir	1.44		0.26
10	Aquaculture		9.83	1.80	
		Fish farm	0.18		0.03
		Shrimp farm	9.65		1.76

Table A3.2 The regroup matrix of land use in 2007 (Continued)

Regroup code	Regroup name	Land use categories (2007)	Area		
			Km^2	%	
11	Settlements		104.61	19.13	
		Agricultural product trading ctr	0.06		0.01
		Airport	1.78		0.33
		Beach	1.84		0.34
		City, Town, Commercial	12.83		2.35
		Factory	1.43		0.26
		Harbour	1.00		0.18
		Institutional land	3.72		0.68
		Recreation area	30.88		5.65
		Road	4.41		0.81
		Village	41.91		7.66
		Village/Coconut	2.65		0.48
		Village/Mixed orchard	2.12		0.39
12	Other land		34.69	6.34	
		Abandoned Aquacultural land	0.17		0.03
		Abandoned mine,pit	26.46		4.84
		Abandoned paddy field	5.31		0.97
		Cemetery	0.03		0.00
		Mine	2.51		0.46
		Poultry farm house	0.16		0.03
		Soil pit	0.06		0.01
13	Scrubland		7.69	1.41	
		Scrub	7.69		1.41
14	N/A		9.34	1.71	
Total			546.83	100	

Table A3.3 The regroup matrix of land use in 2009

Regroup code	Regroup name	Land use categories (2009)	Area		
			Km^2	%	
1	Mangrove		30.14	5.51	
		Dense mangrove forest	28.75		5.26
		Disturbed mangrove forest	1.39		0.25
2	Other forest		97.38	17.81	
		Dense deciduous forest	4.86		0.89
		Dense evergreen forest	92.52		16.92
3	Rubber tree		197.65	36.14	
		Para rubber	197.39		36.10
		Pineapple/Para rubber	0.26		0.05
4	Paddy field		2.36	0.43	
		Rice paddy	2.36		0.43
5	Other agricultural land		20.16	3.69	
		Cashew	0.04		0.01
		Coconut	17.19		3.14
		Durian/Mangosteen	0.12		0.02
		Floricultural	0.02		0.00
		Mixed orchard	0.60		0.11
		Mixed orchard/Coconut	0.06		0.01
		Mixed perennial	0.20		0.04
		Oil palm	1.50		0.27
		Pineapple	0.02		0.00
		Rambutan	0.01		0.00
		Sweet potato	0.00		0.00
		Teak	0.01		0.00
		Truck crop	0.39		0.07
6	Golf course		9.42	1.72	
		Golf course	9.42		1.72
7	Grassland		8.42	1.54	
		Grass	8.12		1.48
		Marsh and Swamp	0.30		0.06

Table A3.3 The regroup matrix of land use in 2009 (Continued)

Regroup code	Regroup name	Land use categories (2009)	Area		
			Km^2	%	
8	Other water body		5.17	0.95	
		Farm pond	1.01		0.18
		Lake	1.48		0.27
		River,Canal	2.69		0.49
9	Reservoir		2.67	0.49	
		Reservoir	2.67		0.49
10	Aquacultue		8.80	1.61	
		Fish farm	0.12		0.02
		Shrimp farm	8.68		1.59
11	Settlements		124.59	22.78	
		Agricultural prodyct trading centers	0.06		0.01
		Airport	1.90		0.35
		Beach	1.84		0.34
		City,Town,Commercial	12.87		2.35
		Factory	2.10		0.38
		Harbour	1.00		0.18
		Institutional land	4.07		0.75
		Recreation area	1.47		0.27
		Road	4.48		0.82
		Village	90.65		16.58
		Village/Coconut	2.05		0.37
		Village/Mixed orchard	2.11		0.38
12	Other land		23.66	4.33	
		Abandoned Aquacultural land	0.17		0.03
		Abandoned mine,pit	17.97		3.29
		Abandoned paddy field	4.30		0.79
		cemetery	0.03		0.00
		Landdfill	0.49		0.09
		Laterite pit	0.07		0.01
		Mine	0.32		0.06

Table A3.3 The regroup matrix of land use in 2009 (Continued)

Regroup code	Regroup name	Land use categories (2009)	Area		
			Km²	%	
12	Other land				
		Poultry farm house	0.16		0.03
		Soil pit	0.06		0.01
		Swine farm house	0.10		0.02
13	Scrubland		7.30	1.33	
		Scrub	7.30		1.33
14	N/A		9.12	1.67	
			9.12		1.67
Total			546.84	100.00	

Table A3.4 The regroup matrix of land use in 2013

Regroup code	Regroup name	Land use categories (2013)	Area		
			Km²	%	
1	Mangrove		28.20	5.16	
		Dense mangrove forest	26.81		4.90
		Disturbed mangrove forest	1.39		0.25
2	Other forest		96.24	17.60	
		Dense deciduous forest	4.83		0.88
		Dense evergreen forest	91.24		16.69
		Disturbed beach forest	0.17		0.03
3	Rubber tree	3	182.23	33.33	
		Para rubber	180.82		33.07
		Pineapple/Para rubber	1.41		0.26
4	Paddy field	4	1.58	0.29	
		Active paddy field	1.58		0.29
5	Other agricultural land	5	19.36	3.54	
		Banana	0.04		0.01
		Cashew	0.05		0.01
		Casuarina	0.16		0.03
		Coconut	14.04		2.57
		Coconut/Banana	0.02		0.00

Table A3.4 The regroup matrix of land use in 2013 (Continued)

Regroup code	Regroup name	Land use categories (2013)	Area		
			Km^2	%	
5	Other agricultural land				
		Coconut/Cashew	0.02		0.00
		Coconut/Truck crop	0.16		0.03
		Corn	0.01		0.00
		Durian	0.03		0.01
		Durian/Mangosteen	0.07		0.01
		Durian/Rambutan	0.02		0.00
		Floricultural/Ornamental plant	0.11		0.02
		Jack fruit	0.04		0.01
		Mangosteen	0.06		0.01
		Mixed orchard	0.61		0.11
		Mixed perennial	0.07		0.01
		Oil palm	3.63		0.66
		Pineapple	0.02		0.00
		Pineapple/Oil palm	0.04		0.01
		Rambutan	0.05		0.01
		Truck crop	0.13		0.02
6	Golf course	6	10.05	1.84	
		Golf course	10.05		1.84
7	Grassland	7	11.03	2.02	
		Grass	10.70		1.96
		Marsh and Swamp	0.29		0.05
		Pasture	0.04		0.01
8	Other water body	8	5.86	1.07	
		Farm pond	0.71		0.13
		Natural water resource	1.96		0.36
		River, Canal	3.20		0.59
9	Reservoir	9	2.91	0.53	
		Reservoir	2.91		0.53

Table A3.4 The regroup matrix of land use in 2013 (Continued)

Regroup code	Regroup name	Land use categories (2013)	Area		
			Km^2	%	
10	Aquacultue	10	8.26	1.51	
		Fish farm	0.17		0.03
		Lotus	0.03		0.01
		Shrimp farm	8.06		1.47
11	Settlements	11	140.86	25.76	
		Agricultural product trading centers	0.04		0.01
		Airport	2.04		0.37
		Beach	1.19		0.22
		City, Town, Commercial	11.76		2.15
		Factory	2.25		0.41
		Harbour	1.27		0.23
		Institutional land	5.76		1.05
		Recreation area	3.29		0.60
		Resort, Hotel, Guesthouse	4.93		0.90
		Road	5.20		0.95
		Thai village	103.15		18.86
12	Other land	12	20.22	3.70	
		Abandoned aquacultural land	0.51		0.09
		Abandoned mine, pit	15.54		2.84
		Abandoned paddy field	3.46		0.63
		Cemetery	0.08		0.02
		Landfill	0.29		0.05
		Material dump	0.01		0.00
		Poultry farm house	0.20		0.04
		Swine farm house	0.12		0.02
13	Scrubland	13	9.88	1.81	
		Scrub	9.88		1.81
14	N/A	99	10.14	1.85	
Total			546.82	100	

Table A3.5 The regroup matrix of land use in 2016

Regroup code	Regroup name	Land use categories (2016)	Area		
			Km^2	%	
1	Mangrove		27.80	5.08	
		Dense mangrove forest	26.24		4.80
		Disturbed mangrove forest	1.57		0.29
2	Other forest		106.15	19.41	
		Dense beach forest	0.36		0.07
		Dense deciduous forest	6.55		1.20
		Dense evergreen forest	98.34		17.98
		Disturbed beach forest	0.79		0.14
		Disturbed deciduous forest	0.08		0.01
		Disturbed evergreen forest	0.02		0.00
3	Rubber tree		161.03	29.45	
		Para rubber	158.02		28.90
		Para rubber/Banana	0.03		0.00
		Pineapple/Para rubber	2.98		0.54
4	Paddy field		0.36	0.07	
		Active paddy field	0.36		0.07
5	Other agricultural land		21.23	3.88	
		Bamboo	0.04		0.01
		Banana	0.18		0.03
		Betel palm	0.01		0.00
		Cashew	0.05		0.01
		Casuarina	0.16		0.03
		Coconut	10.46		1.91
		Coconut/Banana	0.00		0.00
		Coconut/Cashew	0.05		0.01
		Coconut/Truck crop	0.29		0.05
		Durian	0.10		0.02
		Durian/Mangosteen	0.07		0.01
		Durian/Rambutan	0.03		0.01
		Eagle wood	0.01		0.00

Table A3.5 The regroup matrix of land use in 2016 (Continued)

Regroup code	Regroup name	Land use categories (2016)	Area		
			Km^2	%	
5	Other agricultural land				
		Floricultural/Ornamental	0.12		0.02
		Jack fruit	0.03		0.01
		Magosa	0.02		0.00
		Mangosteen	0.10		0.02
		Mangosteen/Langsat	0.01		0.00
		Mixed orchard	1.61		0.29
		Mixed perennial	0.38		0.07
		Mulberry	0.03		0.01
		Oil palm	5.20		0.95
		Papaya	0.01		0.00
		Pineapple	0.79		0.15
		Pineapple/Banana	0.01		0.00
		Pineapple/Mangosteen	0.05		0.01
		Pineapple/Oil palm	0.36		0.07
		Rambutan	0.16		0.03
		Truck crop	0.44		0.08
		Water spinach	0.47		0.09
6	Golf course		8.89	1.63	
		Golf course	8.89		1.63
7	Grassland		10.29	1.88	
		Grass	8.44		1.54
		Marsh and Swamp	1.32		0.24
		Pasture	0.53		0.10
8	Other water body		6.13	1.12	
		Farm pond	0.96		0.18
		Lake, Lagoon	1.96		0.36
		River, Canal	3.21		0.59
9	Reservoir		3.07	0.56	
		Irrigation canal	0.01		0.00
		Reservoir	3.05		0.56

Table A3.5 The regroup matrix of land use in 2016 (Continued)

Regroup code	Regroup name	Land use categories (2016)	Area		
			Km^2	%	
10	Aquacultue		7.85	1.43	
		Fish farm	0.18		0.03
		Lotus	0.03		0.01
		Shrimp farm	7.63		1.40
11	Settlements		153.88	28.14	
		Agricultural product trading center	0.05		0.01
		Airport	2.30		0.42
		Beach	1.21		0.22
		City, Town, Commercial	11.82		2.16
		Factory	3.06		0.56
		Gasoline Station	0.15		0.03
		Harbor	0.42		0.08
		Institutional land	6.99		1.28
		Recreation area	2.56		0.47
		Resort, Hotel, Guesthouse	11.84		2.17
		Road	5.43		0.99
		Village	108.07		19.76
12	Other land		19.76	3.61	
		Abandoned aquacultural land	0.59		0.11
		Abandoned field crop	0.06		0.01
		Abandoned horticulture	0.02		0.00
		Abandoned industrial land	0.04		0.01
		Abandoned mine, Pit	13.75		2.51
		Abandoned paddy field	2.65		0.49
		Abandoned perennial	0.09		0.02
		Abandoned village	0.30		0.06
		Cattle farm house	0.03		0.01
		Cemetery	0.25		0.05
		Landfill	0.75		0.14
		Laterite pit	0.36		0.07

Table A3.5 The regroup matrix of land use in 2016 (Continued)

Regroup code	Regroup name	Land use categories (2016)	Area		
			Km^2	%	
12	Other land				
		Material dump	0.07		0.01
		Mine	0.24		0.04
		Poultry farm house	0.27		0.05
		Soil pit	0.17		0.03
		Swine farm house	0.12		0.02
13	Scrubland		9.68	1.77	
		Shrubland	9.68		1.77
14	N/A		10.73	1.96	
			10.73		1.96
Total			546.84	100	

Table A3.6 The conversion factor for Purchasing Power Party (PPP) and exchange rate

Year	conversion factor for PPP (Thailand) [a]	Exchange rate (USD/Baht) [b]
2000	11.059	40.11
2007	11.546	34.52
2009	11.839	34.29
2013	12.372	30.73
2016	12.446	35.30
2018	12.498	33.94

Source: [a] (World Bank 2019a); [b] (World Bank 2019b)

(iii) Accuracy assessment

The classification of land use/land cover in Phuket employed the 10-fold cross validation method. Therefore, there are 10 table of accuracy assessment from fold 1 to fold 10.

Table A4.1 Accuracy assessment of land use/land cover classification-Fold 1

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	6									6
	Other forest		16	3							19
	Rubber			21	1	1	2				25
	Other agriculture				4						4
	Golf course					2					2
	Grassland			1			3				4
	Other water body							3	1		4
	Aquaculture								2		2
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.898	Kappa	0.873							

Table A4.2 Accuracy assessment of land use/land cover classification-Fold 2

	Ground Truth										Total (Classification / class)
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	
Classification	Mangrove	6									6
	Other forest		14	2							16
	Rubber		2	21	3		3				29
	Other agriculture				2					1	3
	Golf course					3					3
	Grassland			2			2				4
	Other water body							3	1		4
	Aquaculture								2		2
	Settlements									21	21
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.841	Kappa	0.801							

Table A4.3 Accuracy assessment of land use/land cover classification-Fold 3

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	6									6
	Other forest		13		2		1				16
	Rubber		3	20	1		1				25
	Other agriculture			3	2						5
	Golf course					3					3
	Grassland			2			3				5
	Other water body							2	1		3
	Aquaculture							1	2		3
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.830	Kappa	0.788							

Table A4.4 Accuracy assessment of land use/land cover classification-Fold 4

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	5									5
	Other forest	1	13	1			2				17
	Rubber		3	21	1						25
	Other agriculture			3	4						7
	Golf course					2					2
	Grassland					1	3				4
	Other water body							2	1		3
	Aquaculture							1	2		3
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.841	Kappa	0.802							

Table A4.5 Accuracy assessment of land use/land cover classification-Fold 5

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	6									6
	Other forest		14	3	1						18
	Rubber		2	21			1				24
	Other agriculture				4						4
	Golf course					2					2
	Grassland			1		1	4				6
	Other water body							1	1		2
	Aquaculture							2	2		4
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.864	Kappa	0.831							

Table A4.6 Accuracy assessment of land use/land cover classification-Fold 6

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	5									5
	Other forest	1	15	2	2						20
	Rubber		1	21	2						24
	Other agriculture				1		1				2
	Golf course					3	1				4
	Grassland			2			3				5
	Other water body							2			2
	Aquaculture							1	3		4
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.852	Kappa	0.817							

Table A4.7 Accuracy assessment of land use/land cover classification-Fold 7

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	5									5
	Other forest	1	14	1			1				17
	Rubber		2	23	3		1				29
	Other agriculture			1	1						2
	Golf course				1	3					4
	Grassland						3				3
	Other water body							3	1		4
	Aquaculture								2		2
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.864	Kappa	0.829							

Table A4.8 Accuracy assessment of land use/land cover classification-Fold 8

		Ground Truth									
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	5									5
	Other forest		13		1		2			1	17
	Rubber	1	3	25	1		2				32
	Other agriculture				3						3
	Golf course					3					3
	Grassland						1				1
	Other water body							2	1		3
	Aquaculture							1	2		3
	Settlements									21	21
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.852	Kappa	0.813							

Table A4.9 Accuracy assessment of land use/land cover classification-Fold 9

	Ground Truth										
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	6									6
	Other forest		15	1	1		1				18
	Rubber			22							22
	Other agriculture		1		4		1				6
	Golf course			1		2					3
	Grassland			1		1	3				5
	Other water body							2	1		3
	Aquaculture							1	2		3
	Settlements									22	22
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.886	Kappa	0.860							

Table A4.10 Accuracy assessment of land use/land cover classification-Fold 10

		Ground Truth									
	Classes	Mangrove	Other forest	Rubber	Other agriculture	Golf course	Grassland	Other water body	Aquaculture	Settlements	Total (Classification / class)
Classification	Mangrove	6									6
	Other forest		15	3			1				19
	Rubber			22	1	1					24
	Other agriculture		1		4						5
	Golf course					2	1				3
	Grassland						3			1	4
	Other water body							2	1		3
	Aquaculture							1	2		3
	Settlements									21	21
	Total (Ground truth/class)	6	16	25	5	3	5	3	3	22	88
	Overall accuracy	0.875	Kappa	0.845							

(iv) Ground truth data

The ground truth data were collected using Android mobile application, Dioptra, in 2018*.

Table A4.11 Locations of ground truth data

N1	N2	Coordinate		Class name
		X	Y	
1	1	422534	905838	Mangrove forest
2	2	422649	905617	Mangrove forest
3	3	423668	905063	Mangrove forest
4	4	422945	904761	Mangrove forest
5	5	421825	905036	Mangrove forest
6	6	422302	905154	Mangrove forest
7	7	423526	903865	Mangrove forest
8	8	422939	903715	Mangrove forest
9	9	423007	903120	Mangrove forest
10	10	423549	902710	Mangrove forest
11	11	432830	868496	Mangrove forest
12	12	432552	869079	Mangrove forest
13	13	432294	868090	Mangrove forest
14	14	432754	867762	Mangrove forest
15	15	433382	866585	Mangrove forest
16	16	433660	866416	Mangrove forest
17	17	429265	865892	Mangrove forest
18	18	429758	866605	Mangrove forest
19	19	430837	867255	Mangrove forest
20	20	431042	866636	Mangrove forest
21	21	430262	867615	Mangrove forest
22	22	435839	872151	Mangrove forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
23	23	435905	871547	Mangrove forest
24	24	436052	870640	Mangrove forest
25	25	437314	873581	Mangrove forest
26	26	437139	873139	Mangrove forest
27	27	436257	873135	Mangrove forest
28	28	436219	872797	Mangrove forest
29	29	436274	871289	Mangrove forest
30	30	434645	874446	Mangrove forest
39	39	435589	893696	Mangrove forest
40	40	432882	882652	Mangrove forest
41	41	433510	883184	Mangrove forest
42	42	434198	883115	Mangrove forest
43	43	434499	885398	Mangrove forest
44	44	434899	885624	Mangrove forest
45	45	435828	889351	Mangrove forest
46	46	434585	887466	Mangrove forest
47	47	435515	889812	Mangrove forest
48	48	435933	890740	Mangrove forest
49	49	436457	891105	Mangrove forest
50	50	436086	891930	Mangrove forest
51	51	438081	891715	Mangrove forest
52	52	434406	891760	Mangrove forest
53	53	433353	893103	Mangrove forest
54	54	433995	893381	Mangrove forest
55	55	432713	893580	Mangrove forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
56	56	431398	894978	Mangrove forest
57	57	430913	896477	Mangrove forest
58	58	428734	895798	Mangrove forest
59	59	427739	897502	Mangrove forest
60	60	427966	899923	Mangrove forest
Other forest				
61	1	423817	857904	Other forest
62	2	423679	858977	Other forest
63	3	424062	859580	Other forest
64	4	422776	860074	Other forest
65	5	423782	859431	Other forest
66	6	422872	861126	Other forest
67	7	423677	861783	Other forest
68	8	423384	861813	Other forest
69	9	422397	861532	Other forest
70	10	422693	861930	Other forest
71	11	422056	861354	Other forest
72	12	423218	861917	Other forest
73	13	423095	862011	Other forest
74	14	425621	864867	Other forest
75	15	425444	864750	Other forest
76	16	425274	864707	Other forest
77	17	424995	864680	Other forest
78	18	424852	864777	Other forest
79	19	432217	864433	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
80	20	431977	864750	Other forest
81	21	431741	865377	Other forest
82	22	431705	865625	Other forest
83	23	424716	865854	Other forest
84	24	425208	865646	Other forest
85	25	424215	865940	Other forest
86	26	423897	865361	Other forest
87	27	425709	867323	Other forest
88	28	425383	869294	Other forest
89	29	421290	869526	Other forest
90	30	420394	869475	Other forest
91	31	421805	868905	Other forest
92	32	422048	868908	Other forest
93	33	421918	904171	Other forest
94	34	422874	900299	Other forest
95	35	422834	899107	Other forest
96	36	425472	898659	Other forest
97	37	425310	893939	Other forest
98	38	421252	891352	Other forest
99	39	421202	893535	Other forest
100	40	420423	889107	Other forest
101	41	420208	888875	Other forest
102	42	421130	888718	Other forest
103	43	421770	887233	Other forest
104	44	421957	881575	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
105	45	420549	881036	Other forest
106	46	420773	880766	Other forest
107	47	423022	878744	Other forest
108	48	419166	878463	Other forest
109	49	420323	877962	Other forest
110	50	420332	877464	Other forest
111	51	420229	877014	Other forest
112	52	420255	876564	Other forest
113	53	420296	876115	Other forest
114	54	420941	875228	Other forest
115	55	422236	878363	Other forest
116	56	419369	871783	Other forest
117	57	420451	871548	Other forest
118	58	420638	871258	Other forest
119	59	421176	871154	Other forest
120	60	423013	870893	Other forest
121	61	421152	870048	Other forest
122	62	423168	867168	Other forest
123	63	424903	868379	Other forest
124	64	426546	869929	Other forest
125	65	423629	870768	Other forest
126	66	423543	871580	Other forest
127	67	423972	871948	Other forest
128	68	423931	872414	Other forest
129	69	424043	872699	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
130	70	424718	873605	Other forest
131	71	425261	873987	Other forest
132	72	427496	892532	Other forest
133	73	429895	891352	Other forest
134	74	431562	890769	Other forest
135	75	430821	888970	Other forest
136	76	432118	887753	Other forest
137	77	430533	886033	Other forest
138	78	430126	885226	Other forest
139	79	430521	885646	Other forest
140	80	431701	885237	Other forest
141	81	430745	884098	Other forest
142	82	428508	877366	Other forest
143	83	429186	872344	Other forest
144	84	428470	870441	Other forest
145	85	430783	860657	Other forest
146	86	437384	894072	Other forest
147	87	437616	893155	Other forest
148	88	434059	876199	Other forest
149	89	437731	874546	Other forest
150	90	438004	873453	Other forest
151	91	437412	871716	Other forest
152	92	437324	870201	Other forest
153	93	437791	869712	Other forest
154	94	434243	863165	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
155	95	428643	872245	Other forest
156	96	424052	874942	Other forest
157	97	423314	875864	Other forest
158	98	423800	877038	Other forest
159	99	425364	879123	Other forest
160	100	424104	880028	Other forest
161	101	423316	868796	Other forest
162	102	427690	871385	Other forest
163	103	433131	873303	Other forest
164	104	422711	881007	Other forest
165	105	423619	881449	Other forest
166	106	419916	892020	Other forest
167	107	420015	892698	Other forest
168	108	423276	890970	Other forest
169	109	423430	892565	Other forest
170	110	424637	891867	Other forest
171	111	424458	892204	Other forest
172	112	424885	892479	Other forest
173	113	420679	890086	Other forest
174	114	438059	894385	Other forest
175	115	430275	876895	Other forest
176	116	430544	877688	Other forest
177	117	429671	874990	Other forest
178	118	424644	863146	Other forest
179	119	423503	863394	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
180	120	425184	871567	Other forest
181	121	425634	872995	Other forest
182	122	422592	869474	Other forest
183	123	426200	900733	Other forest
184	124	426233	899499	Other forest
185	125	426285	893623	Other forest
186	126	432278	889073	Other forest
187	127	429671	893041	Other forest
188	128	427254	893252	Other forest
189	129	430092	884713	Other forest
190	130	428306	879926	Other forest
191	131	428232	881303	Other forest
192	132	427248	878202	Other forest
193	133	425628	878118	Other forest
194	134	426102	879548	Other forest
195	135	425988	878774	Other forest
196	136	426289	877687	Other forest
197	137	424432	875895	Other forest
198	138	421130	877991	Other forest
199	139	421257	875892	Other forest
200	140	422025	875749	Other forest
201	141	422543	876294	Other forest
202	142	423009	874478	Other forest
203	143	429423	886866	Other forest
204	144	429225	888023	Other forest

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
205	145	431755	891463	Other forest
206	146	437205	889440	Other forest
207	147	437033	889751	Other forest
208	148	430669	896115	Other forest
209	149	425369	896395	Other forest
210	150	426504	895736	Other forest
211	151	429136	876460	Other forest
212	152	425117	876559	Other forest
213	153	435012	872499	Other forest
214	154	434522	866374	Other forest
215	155	433504	865171	Other forest
216	156	433041	864966	Other forest
217	157	433371	864092	Other forest
218	158	432089	866280	Other forest
219	159	432763	866379	Other forest
220	160	430558	890140	Other forest
Rubber				
221	1	423065	903855	Rubber
222	2	424621	904559	Rubber
223	3	424327	903496	Rubber
224	4	424727	901166	Rubber
225	5	424348	900604	Rubber
226	6	424579	899864	Rubber
227	7	424572	902007	Rubber
228	8	425297	901512	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
229	9	424504	897784	Rubber
230	10	424311	899250	Rubber
231	11	423974	898103	Rubber
232	12	424128	897482	Rubber
233	13	424078	898751	Rubber
234	14	425114	898936	Rubber
235	15	424852	899193	Rubber
236	16	425321	899597	Rubber
237	17	425795	899005	Rubber
238	18	425745	897954	Rubber
239	19	426419	897600	Rubber
240	20	427063	898347	Rubber
241	21	426705	897098	Rubber
242	22	426849	896657	Rubber
243	23	429098	894866	Rubber
244	24	428648	894413	Rubber
245	25	429530	895478	Rubber
246	26	430319	895526	Rubber
247	27	430386	896941	Rubber
248	28	423898	858370	Rubber
249	29	423015	862169	Rubber
250	30	424988	859521	Rubber
251	31	422865	861666	Rubber
252	32	425749	864443	Rubber
253	33	424715	864435	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
254	34	426748	864359	Rubber
255	35	426237	863475	Rubber
256	36	425836	863556	Rubber
257	37	425916	862623	Rubber
258	38	424894	862064	Rubber
259	39	426336	861249	Rubber
260	40	423925	861956	Rubber
261	41	423246	861225	Rubber
262	42	426715	865524	Rubber
263	43	425977	865292	Rubber
264	44	424934	865413	Rubber
265	45	425721	865745	Rubber
266	46	424516	865955	Rubber
279	59	431581	868192	Rubber
280	60	432944	866850	Rubber
281	61	422042	868520	Rubber
282	62	421414	870051	Rubber
283	63	423416	870777	Rubber
284	64	426720	870597	Rubber
285	65	437615	874155	Rubber
286	66	437729	873857	Rubber
287	67	436647	872316	Rubber
288	68	438168	872089	Rubber
289	69	438239	871625	Rubber
290	70	437634	871125	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
291	71	437011	871508	Rubber
292	72	429806	872419	Rubber
293	73	430037	874147	Rubber
294	74	433678	875187	Rubber
295	75	434282	876092	Rubber
296	76	433189	876659	Rubber
297	77	434624	877182	Rubber
298	78	433917	876637	Rubber
299	79	434275	874345	Rubber
300	80	431269	878720	Rubber
301	81	431562	878804	Rubber
302	82	431102	879785	Rubber
303	83	428603	878070	Rubber
304	84	420938	875396	Rubber
305	85	420276	877256	Rubber
306	86	420291	878270	Rubber
307	87	422656	878385	Rubber
308	88	420845	880666	Rubber
309	89	420637	882389	Rubber
310	90	421845	888495	Rubber
311	91	420965	888785	Rubber
312	92	420532	888715	Rubber
313	93	421247	888785	Rubber
314	94	421759	888967	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
315	95	421413	893265	Rubber
316	96	422909	893204	Rubber
317	97	422398	892513	Rubber
318	98	423141	892308	Rubber
319	99	422066	891856	Rubber
320	100	421625	891696	Rubber
321	101	422090	890097	Rubber
322	102	429568	880057	Rubber
323	103	428700	880607	Rubber
324	104	429143	881052	Rubber
325	105	429553	881638	Rubber
326	106	430100	881679	Rubber
327	107	428016	882532	Rubber
328	108	428320	882681	Rubber
329	109	428907	884485	Rubber
330	110	428925	883873	Rubber
331	111	430498	882963	Rubber
332	112	429416	883775	Rubber
333	113	431738	880736	Rubber
334	114	433096	883669	Rubber
335	115	431035	883188	Rubber
336	116	430799	883513	Rubber
337	117	432624	884715	Rubber
338	118	431843	884252	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
339	119	434598	883730	Rubber
340	120	434101	883809	Rubber
341	121	435053	883654	Rubber
342	122	434292	884461	Rubber
343	123	424525	884896	Rubber
344	124	425917	884500	Rubber
345	125	427146	884475	Rubber
346	126	426078	883949	Rubber
347	127	426356	883385	Rubber
348	128	427977	883336	Rubber
349	129	427862	883040	Rubber
350	130	425175	883013	Rubber
351	131	424816	882296	Rubber
352	132	426383	882430	Rubber
353	133	425955	882454	Rubber
354	134	428057	882022	Rubber
355	135	427715	881655	Rubber
356	136	427965	880511	Rubber
357	137	427675	880954	Rubber
358	138	427051	881276	Rubber
359	139	426052	881618	Rubber
360	140	425539	881896	Rubber
361	141	426467	881455	Rubber
362	142	425452	880607	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
363	143	426725	880315	Rubber
364	144	423741	886297	Rubber
365	145	424269	885411	Rubber
366	146	424235	887690	Rubber
367	147	424444	888210	Rubber
368	148	423877	887735	Rubber
369	149	424305	888757	Rubber
370	150	424684	889290	Rubber
371	151	426570	889041	Rubber
372	152	427507	889524	Rubber
373	153	428132	889575	Rubber
374	154	426914	888499	Rubber
375	155	428135	885799	Rubber
376	156	426438	885916	Rubber
377	157	426612	886101	Rubber
378	158	429271	886099	Rubber
379	159	429845	885594	Rubber
380	160	431100	885686	Rubber
381	161	430496	885725	Rubber
382	162	429541	885270	Rubber
383	163	430388	886208	Rubber
384	164	428238	888446	Rubber
385	165	428665	888901	Rubber
386	166	429302	888736	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
387	167	429226	889430	Rubber
388	168	424385	894734	Rubber
389	169	424630	894333	Rubber
390	170	424240	890792	Rubber
391	171	424719	889750	Rubber
392	172	424695	890433	Rubber
393	173	425494	890930	Rubber
394	174	426632	890980	Rubber
395	175	427564	890016	Rubber
396	176	427569	890572	Rubber
397	177	427976	890295	Rubber
398	178	427637	891115	Rubber
399	179	426754	891604	Rubber
400	180	426220	891302	Rubber
401	181	426320	892355	Rubber
402	182	425664	892096	Rubber
403	183	426040	891794	Rubber
404	184	427781	892456	Rubber
405	185	428030	891990	Rubber
406	186	427011	893834	Rubber
407	187	429147	893884	Rubber
408	188	430072	894169	Rubber
409	189	430705	893490	Rubber
410	190	425638	883174	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
411	191	426287	902957	Rubber
412	192	431324	883488	Rubber
413	193	433176	884484	Rubber
414	194	433559	884845	Rubber
415	195	433473	885312	Rubber
416	196	433877	887010	Rubber
417	197	434260	888183	Rubber
418	198	433976	888342	Rubber
419	199	433388	889061	Rubber
420	200	434797	889415	Rubber
421	201	434875	888812	Rubber
422	202	431559	892654	Rubber
423	203	431839	893216	Rubber
424	204	431611	893704	Rubber
425	205	432157	892274	Rubber
426	206	432451	892809	Rubber
427	207	433220	892004	Rubber
428	208	434215	890968	Rubber
429	209	434502	891319	Rubber
430	210	434433	892057	Rubber
431	211	434494	892576	Rubber
432	212	435042	891983	Rubber
433	213	435573	892371	Rubber
434	214	435338	892999	Rubber
435	215	435899	893666	Rubber
436	216	436176	893942	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
437	217	437431	895213	Rubber
438	218	437645	894513	Rubber
439	219	437506	894197	Rubber
440	220	437446	892657	Rubber
441	221	437144	892000	Rubber
442	222	432899	891746	Rubber
443	223	433092	891049	Rubber
444	224	433103	890579	Rubber
445	225	433679	889952	Rubber
446	226	434127	890066	Rubber
447	227	436830	891880	Rubber
448	228	437278	891405	Rubber
449	229	437003	890148	Rubber
450	230	434356	886806	Rubber
451	231	425285	874895	Rubber
452	232	437435	877325	Rubber
453	233	422890	891785	Rubber
454	234	427081	900609	Rubber
455	235	433878	884558	Rubber
456	236	432481	886563	Rubber
457	237	430898	884378	Rubber
458	238	431368	886472	Rubber
459	239	436481	893284	Rubber
460	240	427846	895706	Rubber
461	241	424651	896364	Rubber

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
462	242	424983	902790	Rubber
463	243	422529	870850	Rubber
464	244	418997	877775	Rubber
465	245	427600	887737	Rubber
466	246	424245	894022	Rubber
467	247	423859	901606	Rubber
468	248	432233	864900	Rubber
469	249	425217	862907	Rubber
470	250	423026	866317	Rubber
Other agricultural area				
471	1	422295	904618	Other agriculture
472	2	424420	904562	Other agriculture
473	3	423472	900868	Other agriculture
474	4	422885	899210	Other agriculture
475	5	422885	899210	Other agriculture
476	6	423182	898273	Other agriculture
477	7	423528	898372	Other agriculture
478	8	424424	898905	Other agriculture
479	9	426801	897652	Other agriculture
480	10	431849	893126	Other agriculture
481	11	431734	892773	Other agriculture
482	12	435560	892375	Other agriculture
483	13	437466	892630	Other agriculture
484	14	426771	891674	Other agriculture
485	15	426305	891355	Other agriculture

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
486	16	426286	889258	Other agriculture
487	17	428528	888491	Other agriculture
488	18	433856	886576	Other agriculture
489	19	434711	886859	Other agriculture
490	20	434932	886845	Other agriculture
491	21	421913	886918	Other agriculture
492	22	422087	885663	Other agriculture
493	23	424276	885046	Other agriculture
494	24	424352	884844	Other agriculture
495	25	427325	885094	Other agriculture
496	26	420686	882246	Other agriculture
497	27	426344	881503	Other agriculture
498	28	426552	881383	Other agriculture
499	29	429568	880609	Other agriculture
500	30	430364	881046	Other agriculture
501	31	429371	873810	Other agriculture
502	32	429943	873785	Other agriculture
503	33	438096	871582	Other agriculture
504	34	427830	865427	Other agriculture
505	35	427620	865662	Other agriculture
506	36	426485	864273	Other agriculture
507	37	425942	861028	Other agriculture
508	38	423969	857945	Other agriculture
509	39	421982	868402	Other agriculture
510	40	430205	883220	Other agriculture

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
511	41	428030	883097	Other agriculture
512	42	434870	889449	Other agriculture
513	43	434870	889449	Other agriculture
514	44	421680	860250	Other agriculture
515	45	424130	862831	Other agriculture
516	46	425374	901847	Other agriculture
517	47	424715	903119	Other agriculture
518	48	429043	889798	Other agriculture
519	49	433381	890787	Other agriculture
520	50	426041	901603	Other agriculture
Golf course				
521	1	424886	895615	Golf course
522	2	425467	895998	Golf course
523	3	426245	896161	Golf course
524	4	426182	895347	Golf course
525	5	425523	895033	Golf course
526	6	425471	894613	Golf course
527	7	430823	894266	Golf course
528	8	431725	894256	Golf course
529	9	431388	894008	Golf course
530	10	430735	893774	Golf course
531	11	422636	885399	Golf course
532	12	422803	884727	Golf course
533	13	423253	885302	Golf course
534	14	422615	885974	Golf course

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
535	15	426604	877153	Golf course
536	16	426758	876122	Golf course
537	17	427275	876736	Golf course
538	18	426826	877346	Golf course
539	19	427865	875806	Golf course
540	20	428605	875375	Golf course
541	21	429062	875641	Golf course
542	22	427926	873805	Golf course
543	23	427339	873668	Golf course
544	24	427151	872641	Golf course
545	25	427701	872908	Golf course
546	26	428015	873176	Golf course
547	27	428064	872726	Golf course
548	28	426699	868502	Golf course
549	29	426239	868588	Golf course
550	30	428291	876199	Golf course
551	1	422088	905947	Grassland
552	2	421665	905255	Grassland
553	3	422615	903385	Grassland
554	4	422545	902304	Grassland
555	5	424390	901894	Grassland
556	6	423277	900159	Grassland
557	7	423097	899215	Grassland
558	8	424003	897830	Grassland
559	9	430434	893655	Grassland

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
560	10	432325	892825	Grassland
561	11	426643	895586	Grassland
562	12	427501	893611	Grassland
563	13	426824	894331	Grassland
564	14	433608	891686	Grassland
565	15	434289	888544	Grassland
566	16	435253	888773	Grassland
567	17	434127	884015	Grassland
568	18	431136	883251	Grassland
569	19	429116	882394	Grassland
570	20	425486	859555	Grassland
571	21	423319	891525	Grassland
572	22	427072	886370	Grassland
573	23	424474	886395	Grassland
574	24	424742	889109	Grassland
575	25	424651	890108	Grassland
576	26	426030	889308	Grassland
577	27	426481	890516	Grassland
578	28	424047	884165	Grassland
579	29	422079	887945	Grassland
580	30	424056	882986	Grassland
581	31	424855	882484	Grassland
582	32	426999	884896	Grassland
583	33	426205	883155	Grassland
584	34	426653	881573	Grassland

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
585	35	426904	880826	Grassland
586	36	432055	881097	Grassland
587	37	430221	882138	Grassland
588	38	431698	867897	Grassland
589	39	426777	864193	Grassland
590	40	425436	865749	Grassland
591	41	425605	866141	Grassland
592	42	430314	878762	Grassland
593	43	430660	873912	Grassland
594	44	437536	873027	Grassland
595	45	434614	873081	Grassland
596	46	431541	877659	Grassland
597	47	423685	885516	Grassland
598	48	426429	872784	Grassland
599	49	422052	879016	Grassland
600	50	429549	869393	Grassland
Other water body				
601	1	422627	905303	Other water body
602	2	423455	904398	Other water body
603	3	422535	902030	Other water body
604	4	424437	886502	Other water body
605	5	424579	886321	Other water body
606	6	432957	881255	Other water body
607	7	432614	880601	Other water body
608	8	431457	876599	Other water body

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
609	9	435486	871401	Other water body
610	10	434524	870745	Other water body
611	11	430795	867117	Other water body
612	12	426332	869061	Other water body
613	13	428875	869455	Other water body
614	14	425780	860536	Other water body
615	15	422110	868025	Other water body
616	16	421423	871637	Other water body
617	17	424466	889673	Other water body
618	18	426772	894010	Other water body
619	19	424045	900731	Other water body
620	20	422901	899928	Other water body
621	21	423210	897676	Other water body
622	22	428567	898029	Other water body
623	23	427852	896897	Other water body
624	24	433608	893077	Other water body
625	25	435910	890447	Other water body
626	26	433745	882998	Other water body
627	27	431079	881004	Other water body
628	28	433044	877320	Other water body
629	29	422983	879950	Other water body
630	30	425342	887088	Other water body
631	1	432717	892575	Aqualculture
632	2	435324	891269	Aqualculture
633	3	437353	892278	Aqualculture

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
634	4	437499	892485	Aqualculture
635	5	436904	889856	Aqualculture
636	6	435551	888617	Aqualculture
637	7	435055	888962	Aqualculture
638	8	433804	885052	Aqualculture
639	9	431108	882070	Aqualculture
640	10	432442	880792	Aqualculture
641	11	433507	878460	Aqualculture
642	12	434102	877305	Aqualculture
643	13	430761	895296	Aqualculture
644	14	423404	903027	Aqualculture
645	15	423998	904408	Aqualculture
646	16	427347	897354	Aqualculture
647	17	429564	868369	Aqualculture
648	18	430942	866868	Aqualculture
649	19	431988	868318	Aqualculture
650	20	434637	870784	Aqualculture
651	21	437000	872802	Aqualculture
652	22	433598	883796	Aqualculture
653	23	432804	883287	Aqualculture
654	24	427601	899008	Aqualculture
655	25	433975	891321	Aqualculture
656	26	434252	893020	Aqualculture
657	27	431890	893944	Aqualculture
658	28	434320	887378	Aqualculture

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
659	29	434748	885629	Aqualculture
660	30	429539	896589	Aqualculture
Settlments				
661	1	422783	906030	Settlements
662	2	422353	906275	Settlements
663	3	422026	906058	Settlements
664	4	422115	904191	Settlements
665	5	422867	904396	Settlements
666	6	422671	903068	Settlements
667	7	422495	902497	Settlements
668	8	422600	901896	Settlements
669	9	422662	901424	Settlements
670	10	422959	900582	Settlements
671	11	423353	904205	Settlements
672	12	424217	903751	Settlements
673	13	424084	902840	Settlements
674	14	423600	901837	Settlements
675	15	424162	902406	Settlements
676	16	424614	901319	Settlements
677	17	424975	901844	Settlements
678	18	425460	901581	Settlements
679	19	424281	899814	Settlements
680	20	424396	900067	Settlements
681	21	423634	899926	Settlements
682	22	424002	858155	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate X	Coordinate Y	Class name
683	23	424470	858710	Settlements
684	24	425523	859375	Settlements
685	25	424784	859442	Settlements
686	26	423329	859851	Settlements
687	27	424007	860244	Settlements
688	28	424504	860203	Settlements
689	29	425778	859981	Settlements
690	30	426211	860647	Settlements
691	31	425390	860301	Settlements
692	32	425533	861415	Settlements
693	33	424755	860905	Settlements
694	34	423513	861749	Settlements
695	35	425032	861789	Settlements
696	36	424052	861741	Settlements
697	37	426374	861670	Settlements
698	38	426094	862198	Settlements
699	39	426777	862415	Settlements
700	40	427089	863431	Settlements
701	41	426522	863206	Settlements
702	42	427155	864393	Settlements
703	43	425094	862465	Settlements
704	44	425795	863278	Settlements
705	45	426179	864259	Settlements
706	46	423469	864426	Settlements
707	47	424580	864579	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
708	48	434440	862866	Settlements
709	49	434680	863305	Settlements
710	50	433857	863832	Settlements
711	51	433852	864571	Settlements
712	52	433948	865099	Settlements
713	53	433847	865859	Settlements
714	54	436313	870570	Settlements
715	55	434516	871215	Settlements
716	56	433377	871731	Settlements
717	57	435696	872139	Settlements
718	58	436398	871809	Settlements
719	59	437911	871294	Settlements
720	60	438020	872669	Settlements
721	61	437033	872465	Settlements
722	62	433763	874346	Settlements
723	63	434394	874605	Settlements
724	64	434301	873273	Settlements
725	65	433427	878063	Settlements
726	66	433391	877507	Settlements
727	67	434207	875401	Settlements
728	68	433444	875558	Settlements
729	69	433721	876006	Settlements
730	70	434056	877162	Settlements
731	71	435852	883256	Settlements
732	72	434769	883450	Settlements
733	73	433373	885122	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
734	74	433845	885788	Settlements
735	75	433920	886950	Settlements
736	76	433998	887725	Settlements
737	77	434499	888795	Settlements
738	78	434621	889494	Settlements
739	79	435059	890064	Settlements
740	80	433837	890060	Settlements
741	81	433729	891276	Settlements
742	82	437047	890281	Settlements
743	83	437411	891144	Settlements
744	84	438277	891896	Settlements
745	85	437695	891631	Settlements
746	86	435940	892041	Settlements
747	87	437718	894037	Settlements
748	88	430669	897625	Settlements
749	89	429777	897101	Settlements
750	90	429576	894445	Settlements
751	91	428431	891983	Settlements
752	92	432536	892343	Settlements
753	93	432151	893023	Settlements
754	94	432414	893657	Settlements
755	95	428736	889833	Settlements
756	96	428777	884831	Settlements
757	97	428725	885783	Settlements
758	98	429600	885380	Settlements
759	99	432811	883879	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
760	100	431658	883512	Settlements
761	101	430798	882802	Settlements
762	102	428796	884204	
763	103	428724	882583	Settlements
764	104	430469	881778	Settlements
765	105	429999	881400	Settlements
766	106	431628	880024	Settlements
767	107	432623	879442	Settlements
768	108	430604	878899	Settlements
769	109	432913	875211	Settlements
770	110	431781	875872	Settlements
771	111	430568	875374	Settlements
772	112	431378	877305	Settlements
807	147	424087	894881	Settlements
808	148	423672	891067	Settlements
809	149	427096	891787	Settlements
810	150	427567	892138	Settlements
811	151	427761	892606	Settlements
812	152	427496	893834	Settlements
813	153	427291	894562	Settlements
814	154	426878	885150	Settlements
815	155	427861	885109	Settlements
816	156	426892	886679	Settlements
817	157	428062	888220	Settlements
818	158	427301	889245	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
819	159	426587	887852	Settlements
820	160	425515	889185	Settlements
821	161	423600	886479	Settlements
822	162	424864	886049	Settlements
823	163	424575	885326	Settlements
824	164	426821	884253	Settlements
825	165	424056	884437	Settlements
826	166	423415	883854	Settlements
827	167	423420	883169	Settlements
828	168	425823	883072	Settlements
829	169	426710	882070	Settlements
830	170	427871	880677	Settlements
831	171	427294	881439	Settlements
832	172	424241	865311	Settlements
833	173	426241	865843	Settlements
834	174	426574	864912	Settlements
835	175	427242	865288	Settlements
836	176	426592	867321	Settlements
837	177	427456	865890	Settlements
838	178	426190	869033	Settlements
839	179	426899	869073	Settlements
840	180	427432	868589	Settlements
841	181	426271	874299	Settlements
842	182	426129	873768	Settlements
843	183	423999	873480	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
844	184	423787	872287	Settlements
845	185	423631	870970	Settlements
846	186	423020	865163	Settlements
847	187	422641	865938	Settlements
848	188	422892	867179	Settlements
849	189	422622	867523	Settlements
850	190	422258	868046	Settlements
851	191	421062	869053	Settlements
852	192	421758	870765	Settlements
853	193	422134	871343	Settlements
854	194	419978	871514	Settlements
855	195	421466	871701	Settlements
856	196	422796	871858	Settlements
857	197	422456	872623	Settlements
858	198	422533	873414	Settlements
859	199	422435	874494	Settlements
860	200	422870	899334	Settlements
861	201	422986	898677	Settlements
862	202	421166	880299	Settlements
863	203	420534	881693	Settlements
864	204	421404	882736	Settlements
865	205	422192	882104	Settlements
866	206	422805	884014	Settlements
867	207	422453	884532	Settlements
868	208	421104	879515	Settlements

Table A4.11 Locations of ground truth data (Continued)

N1	N2	Coordinate		Class name
		X	Y	
869	209	421663	878746	Settlements
870	210	422872	878497	Settlements
871	211	420720	878831	Settlements
872	212	419632	878503	Settlements
873	213	421511	875270	Settlements
874	214	422696	885159	Settlements
875	215	422215	887632	Settlements
876	216	422006	888413	Settlements
877	217	420463	890909	Settlements
878	218	421985	891676	Settlements
879	219	422582	892451	Settlements
880	220	422048	868966	Settlements

*WGS_1984_UTM_ZONE_47N

(iv) Environmental protection map and data verification

In this section, the change area in environmental protection map was identify by overlapping Settlements layer of Phuket land use 2018 with forest and agricultural conservation area. The verification of elevation in each change area was observed and presented with following table.

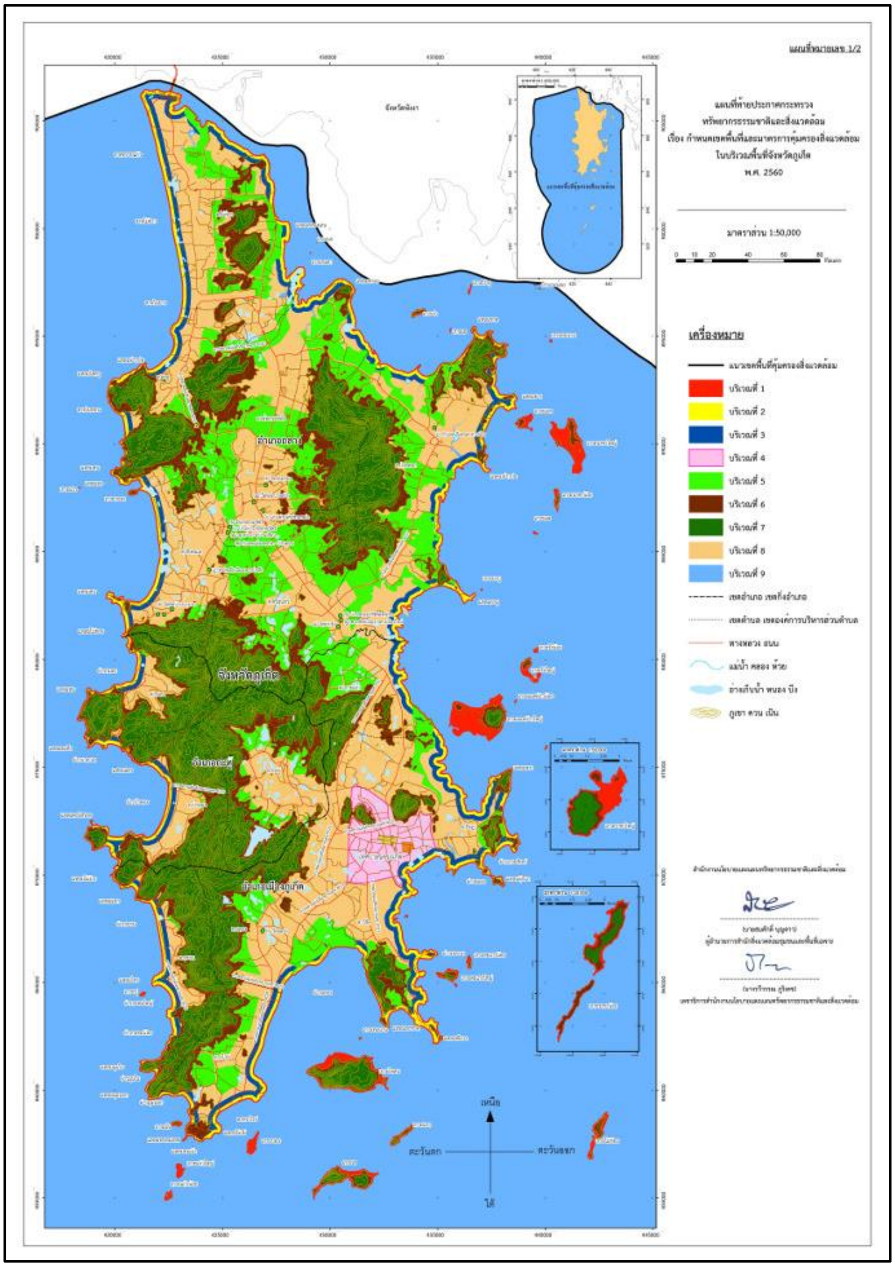

Figure A4.1 Environmental protection area in Phuket province

Table A4.12 Sub-categories of Phuket GPP main group

Phuket GPP	
Main group	**Sub-categories**
Agriculture	Agriculture, forestry and fishing
Non-Agriculture	Mining and quarrying
	Manufacturing
	Electricity, gas, steam and air conditioning supply
	Water supply; sewerage, waste management and remediation activities
	Construction
	Wholesale and retail trade; repair of motor vehicles and motorcycles
	Transportation and storage
	Accommodation and food service activities
	Information and communication
	Financial and insurance activities
	Real estate activities
	Professional, scientific and technical activities
	Administrative and support service activities
	Public administration and defence; compulsory social security
	Education
	Human health and social work activities
	Arts, entertainment and recreation
	Other service activities

Table A4.13 The coordination of the checked locations (hotel, restaurant and resort)

N	y_proj	x_proj	Elevation		Remark
			GPS	Google	
1	875774	430343	96.04	108	
2	878487	429686	88.15	109	
3	877759	429083	88.65	0	
4	876994	425651	108.49	108	
5	876823	425043	83.98	85	
6	875900	425533	89.95	90	
7	875739	425803	88.93	100	
8	871213	420929	127.34	163	
9	871354	421055	91.53	96	
10	874216	423659	89.43	111	
11	873727	424314	79.11	88	
12	873880	425356	101.58	143	
13	862562	424774	105.72	116	
14	861707	423514	90.89	97	
15	861595	423630	83.5	99	
16	861450	423351	101.12	125	
17	862177	422825	142.82	153	
18	862537	423494	117.06	122	
19	865941	423480	79.65	83	
20	866093	423628	106.88	144	
21	866446	423671	133.76	158	
22	864569	424565	81.41	90	
23	864401	424500	84.78	87	
24	864236	424420	83.66	93	
25	864026	424373	116.61	128	

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
26	863887	424315	130.75	133	
27	863544	424209	169.97	183	
28	864567	424721	88	100	
29	864597	425006	91.97	115	
30	864659	425286	89.38	98	
31	865128	425650	81.08	112	
32	863353	425548	101.67	101	
33	865693	424760	217.58	231	
34	865658	425355	103.92	115	
35	866480	425637	82.35	87	
36	867547	425896	109.82	0	
37	869272	425141	93.72	87	
38	869556	426121	79.14	0	
39	869556	426121	80.02	0	
40	869791	426009	167.22	176	
41	869991	426114	196.69	206	
42	870236	427862	122.87	133	
43	870573	427965	194.99	201	
44	870385	428244	152.21	0	
45	878210	422692	84.8	90	
46	877568	422351	84.76	0	
47	878239	418865	82.57	87	
48	877467	418537	102.73	83	
49	877441	418591	95.03	0	
50	876988	418777	102	108	

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
51	876849	418969	154.43	156	
52	876515	418932	100.22	112	
53	876522	419521	94.8	112	
54	877464	420687	87.01	94	
55	877119	420705	150	0	
56	876902	420317	82.15	89	
57	874151	423053	83.55	0	
58	872598	423876	84.47	86	
59	872292	423779	120.22	121	
60	871208	423384	138.19	147	
61	870989	423605	172.48	160	
62	870686	423586	151.74	152	
63	870864	423241	106.45	148	
64	870296	423041	141.33	156	
65	870694	422919	106.56	152	
66	870486	422100	93.96	113	
67	870487	422279	127.84	181	
68	870320	421576	86.18	97	
69	869076	421170	85.65	0	
70	868940	421495	91.11	92	
71	867839	423454	99.79	108	
72	867643	423677	118.36	112	
73	867477	423266	111.32	102	
74	865270	423481	80.07	0	
75	872929	431543	0	0	Exceptional case

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
76	869603	425857	0	153	Exceptional case
77	871235	424617	0	0	Exceptional case
78	899262	426193	0	258	Exceptional case
79	873222	424859	0	234	Exceptional case
80	867168	423995	0	150	Exceptional case
81	865305	424221	0	392	Exceptional case
82	899167	426147	0	248	Exceptional case
83	872455	431945	0	94	Exceptional case
84	871086	436711	0	71	Exceptional case
85	865348	432556	0	90	Exceptional case
86	866084	432116	0	163	Exceptional case
87	877041	428331	0	98	Exceptional case
88	876997	428005	0	86	Exceptional case
89	861937	423071	0	191	Exceptional case
90	873045	433353	0	248	Exceptional case
91	891302	421422	0	88	
92	888642	420230	0	85	
93	889481	422529	0	115	
94	887663	422962	0	88	
95	879164	422757	0	81	
96	876805	420420	0	106	
97	876268	421079	0	132	
98	875973	420496	0	90	
99	875332	421242	0	102	
100	875659	422424	0	100	
101	875459	421882	0	127	

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
102	874974	422630	0	94	
103	865852	424035	0	327	
104	864957	423306	0	95	
105	865620	431936	0	100	
106	872918	433651	0	96	
107	873855	433254	0	92	
108	873014	430903	0	94	
109	872573	429165	0	81	
110	891958	432033	0	87	
111	877116	426318	0	128	
112	870948	422670	0	62	
113	871611	421148	0	80	
114	871250	420417	0	82	
115	870422	421354	0	95	
116	870353	421317	0	97	
117	867965	422882	0	88	
118	864004	425791	0	94	
119	866269	425300	0	93	
120	869841	427127	0	109	
121	874308	425527	0	84	
122	874973	425488	0	87	
123	862456	423512	0	131	
124	891999	431969	0	83	
125	885430	432915	0	0	Non verified location
126	900266	425663	0	0	Non verified location
127	891454	421168	0	0	Non verified location

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
128	890099	420505	0	0	Non verified location
129	889914	420665	0	0	Non verified location
130	888648	421146	0	0	Non verified location
131	887886	423028	0	0	Non verified location
132	887081	423033	0	0	Non verified location
133	881364	422166	0	0	Non verified location
134	881517	421208	0	0	Non verified location
135	880416	421542	0	0	Non verified location
136	877144	421137	0	0	Non verified location
137	878336	419883	0	0	Non verified location
138	876401	420380	0	0	Non verified location
139	875544	421739	0	0	Non verified location
140	875314	422630	0	0	Non verified location
141	874641	422699	0	0	Non verified location
142	874429	422773	0	0	Non verified location
143	874239	422890	0	0	Non verified location
144	873520	424544	0	0	Non verified location
145	873536	425128	0	0	Non verified location
146	869340	424322	0	0	Non verified location
147	862214	423654	0	0	Non verified location
148	866030	431883	0	0	Non verified location
149	865599	432226	0	0	Non verified location
150	873485	434503	0	0	Non verified location
151	873440	430828	0	0	Non verified location
152	872821	430864	0	0	Non verified location

Table A4.13 The coordination of the checked locations (Continued)

N	y_proj	x_proj	Elevation		Remarks
			GPS	Google	
153	872721	430793	0	0	Non verified location
154	872581	430797	0	0	Non verified location
155	885262	432890	0	0	Non verified location
156	884994	432902	0	0	Non verified location
157	884733	429796	0	0	Non verified location
158	884934	432890	0	0	Non verified location
159	877108	437819	0	0	Non verified location
160	872944	431240	0	0	Non verified location
161	877468	426553	0	0	Non verified location
162	891686	425078	0	0	Non verified location
163	878003	432505	0	0	Non verified location
164	870213	421095	0	0	Non verified location
165	870265	421791	0	0	Non verified location
166	871063	427168	0	0	Non verified location
167	870901	426766	0	0	Non verified location
168	872905	425227	0	0	Non verified location
169	872516	431835	0	0	Non verified location
170	876528	433807	0	0	Non verified location
171	874562	425504	0	0	Non verified location

(v) Land use change matrix in Phuket in each period

In this section, the land use change matrix in Phuket by each period (2000-2007, 2007-2009, 2009-2013, 2013-2016, 2016-2018) was illustrated in the table below.

Table A4.14 Land use change matrix in Phuket from 2000 to 2007

Type of land use		Land use (2007)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Land use (2000)	1	15.62	0.00	0.50	0.01	0.29	0.00	0.01	0.50	0.00	1.33	0.74	0.00	0.10	0.85	19.95
	2	4.40	47.71	14.66	0.00	1.01	0.04	0.25	0.31	0.00	0.11	3.79	1.38	0.96	2.55	77.17
	3	2.67	45.58	165.10	0.14	5.35	2.12	2.47	0.53	0.46	1.54	18.00	8.96	2.03	1.69	256.66
	4	0.04	0.00	1.59	2.61	0.35	0.00	1.95	0.13	0.01	0.11	1.55	3.98	0.06	0.00	12.37
	5	0.82	0.78	4.91	0.00	8.24	0.00	0.33	0.22	0.00	0.60	7.90	0.54	0.42	1.16	25.91
	6	0.00	0.06	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.72
	7	0.11	0.00	0.57	0.00	0.89	0.01	0.50	0.16	0.00	0.01	1.00	0.21	0.31	0.02	3.78
	8*															
	9	0.00	0.13	0.13	0.00	0.15	0.00	0.00	0.25	0.45	0.00	0.03	0.00	0.00	0.00	1.14
	10	1.74	0.02	0.82	0.03	0.39	0.00	0.26	0.19	0.00	5.35	1.32	0.15	0.13	0.37	10.79
	11	0.97	1.99	7.54	0.40	3.10	2.96	1.55	0.84	0.29	0.17	54.34	4.20	1.81	1.89	82.05
	12	0.45	2.63	4.93	0.09	1.52	0.01	2.60	0.42	0.22	0.14	10.96	15.04	1.76	0.27	41.05
	13	0.00	0.03	0.16	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.22	0.00	0.00	0.47
	14	3.99	2.22	0.58	0.00	0.54	0.00	0.03	1.39	0.01	0.44	4.92	0.01	0.11	0.54	14.78
Total		30.80	101.18	201.48	3.27	21.86	5.79	9.94	4.94	1.44	9.82	104.60	34.68	7.69	9.33	546.83

* In 2000, the land use type of Other water body is not available

Table A4.15 Land use change matrix in Phuket from 2007 to 2009

Type of land use		Land use (2009)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Land use (2007)	1	30.08	0.00	0.01	0.00	0.00	0.25	0.16	0.00	0.00	0.00	0.31	0.00	0.00	0.00	30.80
	2	0.00	97.40	0.30	0.00	0.01	0.00	0.00	0.00	0.00	0.00	3.48	0.00	0.00	0.00	101.18
	3	0.06	0.00	195.95	0.00	0.34	0.54	0.09	0.01	0.79	0.00	3.40	0.28	0.02	0.00	201.48
	4	0.00	0.00	0.02	2.35	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.26	0.00	0.00	3.27
	5	0.00	0.00	0.69	0.01	19.67	0.00	0.05	0.00	0.06	0.00	1.38	0.00	0.00	0.00	21.86
	6	0.00	0.00	0.00	0.00	0.00	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.79
	7	0.00	0.00	0.07	0.00	0.01	0.00	7.45	0.00	0.00	0.00	2.22	0.19	0.00	0.00	9.94
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.94	0.00	0.00	0.00	0.00	0.00	0.00	4.94
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	0.00	0.00	0.00	0.00	0.00	1.44
	10	0.00	0.00	0.37	0.00	0.00	0.00	0.01	0.00	0.00	8.79	0.35	0.30	0.00	0.00	9.82
	11	0.00	0.00	0.11	0.00	0.10	0.00	0.03	0.00	0.00	0.00	104.23	0.10	0.02	0.00	104.60
	12	0.00	0.00	0.05	0.00	0.04	2.84	0.53	0.00	0.39	0.00	8.32	22.38	0.14	0.00	34.68
	13	0.00	0.00	0.08	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.26	0.14	7.12	0.00	7.69
	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	9.11	9.33
Total		30.14	97.40	197.64	2.36	20.17	9.42	8.43	5.17	2.67	8.79	124.58	23.65	7.30	9.11	546.83

1. Mangrove
2. Other forest
3. Rubber
4. Paddy field
5. Other agricultural area
6. Golf course
7. Grassland
8. Other water body
9. Reservoir
10. Aquaculture
11. Settlements
12. Other land
13. Scrubland
14. N/A

Table A4.16 Land use change matrix in Phuket from 2009 to 2013

Type of land use		Land use (2013)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Land use (2009)	1	27.80	0.13	0.06	0.00	0.17	0.01	0.01	0.48	0.00	0.10	0.80	0.01	0.49	0.08	30.14
	2	0.00	91.80	3.17	0.00	0.08	0.08	0.10	0.00	0.01	0.00	2.04	0.03	0.08	0.01	97.40
	3	0.09	2.20	176.43	0.00	2.14	0.00	2.94	0.04	0.14	0.08	11.59	0.32	1.65	0.01	197.64
	4	0.00	0.00	0.22	1.55	0.02	0.00	0.00	0.00	0.00	0.00	0.35	0.21	0.00	0.00	2.36
	5	0.10	0.14	0.95	0.00	15.08	0.00	0.63	0.05	0.00	0.04	2.90	0.01	0.24	0.02	20.17
	6	0.01	0.00	0.00	0.00	0.00	9.18	0.00	0.00	0.00	0.00	0.04	0.19	0.00	0.00	9.42
	7	0.02	0.00	0.24	0.00	0.28	0.00	5.49	0.08	0.00	0.01	1.95	0.02	0.34	0.00	8.43
	8	0.08	0.02	0.02	0.00	0.02	0.00	0.02	4.55	0.00	0.00	0.22	0.18	0.05	0.00	5.17
	9	0.00	0.01	0.06	0.00	0.00	0.07	0.00	0.08	2.23	0.00	0.09	0.13	0.00	0.00	2.67
	10	0.02	0.00	0.06	0.00	0.12	0.00	0.01	0.01	0.00	7.80	0.25	0.48	0.04	0.00	8.79
	11	0.06	1.93	0.51	0.00	0.79	0.48	1.36	0.49	0.53	0.00	115.28	0.92	0.56	1.69	124.58
	12	0.00	0.01	0.27	0.01	0.52	0.23	0.05	0.05	0.00	0.16	3.68	17.69	0.99	0.00	23.65
	13	0.02	0.00	0.23	0.00	0.14	0.00	0.41	0.03	0.00	0.06	0.93	0.04	5.43	0.00	7.30
	14	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	8.32	9.11
Total		28.20	96.25	182.24	1.58	19.36	10.05	11.02	5.86	2.91	8.26	140.88	20.22	9.88	10.14	546.83

1. Mangrove
2. Other forest
3. Rubber
4. Paddy field
5. Other agricultural area
6. Golf course
7. Grassland
8. Other water body
9. Reservoir
10. Aquaculture
11. Settlements
12. Other land
13. Scrubland
14. N/A

Table A4.17 Land use change matrix in Phuket from 2013 to 2016

Type of land use		Land use (2016)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Land use (2013)	1	26.93	0.05	0.09	0.00	0.07	0.02	0.08	0.09	0.00	0.03	0.49	0.03	0.06	0.25	28.20
	2	0.10	91.96	2.07	0.00	0.37	0.01	0.04	0.00	0.08	0.02	1.28	0.19	0.00	0.13	96.25
	3	0.12	9.65	156.40	0.00	4.27	0.00	1.81	0.10	0.11	0.08	7.14	1.30	1.21	0.05	182.24
	4	0.00	0.00	0.05	0.34	0.14	0.00	0.11	0.00	0.00	0.00	0.18	0.72	0.04	0.00	1.58
	5	0.08	1.01	0.56	0.00	14.37	0.00	0.56	0.06	0.00	0.00	2.05	0.12	0.54	0.01	19.36
	6	0.00	0.06	0.00	0.00	0.00	8.77	0.00	0.00	0.02	0.00	0.78	0.30	0.11	0.00	10.05
	7	0.05	0.23	0.32	0.01	0.48	0.00	6.44	0.05	0.04	0.02	2.24	0.14	1.00	0.00	11.02
	8	0.01	0.02	0.03	0.00	0.02	0.00	0.01	5.50	0.00	0.00	0.16	0.00	0.01	0.10	5.86
	9	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00	2.77	0.00	0.02	0.00	0.01	0.00	2.91
	10	0.13	0.01	0.03	0.00	0.07	0.00	0.00	0.00	0.01	7.55	0.16	0.26	0.04	0.00	8.26
	11	0.22	0.93	1.13	0.02	0.59	0.06	0.54	0.11	0.01	0.08	135.89	0.63	0.43	0.23	140.88
	12	0.00	0.10	0.14	0.00	0.64	0.02	0.58	0.12	0.00	0.00	2.53	15.90	0.19	0.00	20.22
	13	0.13	1.98	0.17	0.00	0.19	0.01	0.12	0.08	0.01	0.07	0.90	0.17	6.05	0.00	9.88
	14	0.02	0.07	0.02	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.05	0.00	0.00	9.95	10.14
Total		27.80	106.15	161.02	0.36	21.22	8.89	10.29	6.13	3.07	7.84	153.87	19.77	9.68	10.73	546.83

1. Mangrove
2. Other forest
3. Rubber
4. Paddy field
5. Other agricultural area
6. Golf course
7. Grassland
8. Other water body
9. Reservoir
10. Aquaculture
11. Settlements
12. Other land
13. Scrubland
14. N/A

Table A4.18 Land use change matrix in Phuket from 2016 to 2018

Type of land use		Land use (2018)														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	99	
Land use (2016)	1	26.12	0.00	0.01	0.00	0.16	0.00	0.01	0.95	0.00	0.10	0.41	0.01	0.02	0.01	27.80
	2	0.00	101.59	1.01	0.00	0.94	0.02	0.04	0.11	0.00	0.00	2.39	0.02	0.01	0.02	106.15
	3	0.01	0.18	156.40	0.00	0.81	0.00	0.02	0.00	0.00	0.01	3.53	0.02	0.04	0.00	161.02
	4	0.00	0.00	0.00	0.28	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.36
	5	0.04	0.35	0.05	0.00	17.76	0.00	0.12	0.09	0.00	0.03	2.68	0.01	0.08	0.00	21.22
	6	0.02	0.07	0.00	0.00	0.01	8.67	0.01	0.02	0.00	0.00	0.08	0.01	0.01	0.00	8.89
	7	0.00	0.03	0.04	0.00	1.01	0.00	6.86	0.04	0.00	0.01	2.18	0.01	0.09	0.00	10.29
	8	0.25	0.03	0.01	0.00	0.08	0.01	0.06	5.12	0.00	0.10	0.43	0.01	0.04	0.00	6.13
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.06	0.00	0.00	0.00	0.00	0.00	3.07
	10	0.14	0.01	0.01	0.00	0.08	0.00	0.01	0.07	0.00	7.33	0.14	0.01	0.04	0.00	7.84
	11	0.34	0.80	0.25	0.00	1.53	0.20	0.35	0.30	0.00	0.68	149.15	0.05	0.20	0.02	153.87
	12	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	19.70	0.01	0.00	19.77
	13	0.04	0.05	0.01	0.00	0.39	0.00	0.34	0.02	0.00	0.01	1.38	0.01	7.43	0.00	9.68
	99	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.02	0.00	0.00	10.63	10.73
Total		26.98	103.12	157.81	0.29	22.80	8.92	7.83	6.77	3.07	8.27	162.47	19.84	7.98	10.69	546.83

1. Mangrove
2. Other forest
3. Rubber
4. Paddy field
5. Other agricultural area
6. Golf course
7. Grassland
8. Other water body
9. Reservoir
10. Aquaculture
11. Settlements
12. Other land
13. Scrubland
14. N/A

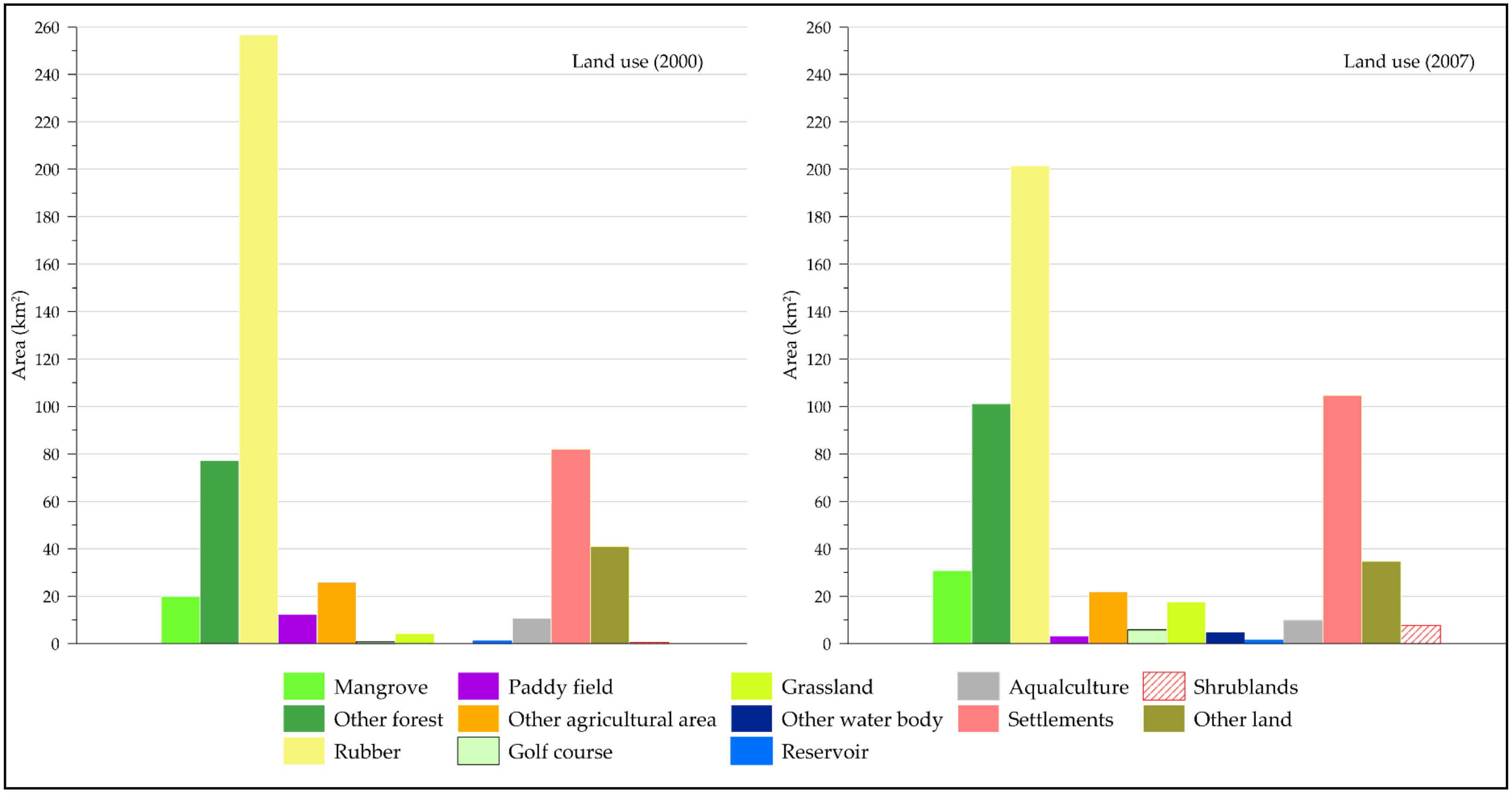

Figure A4.2 The area of land use in year 2000, and 2007

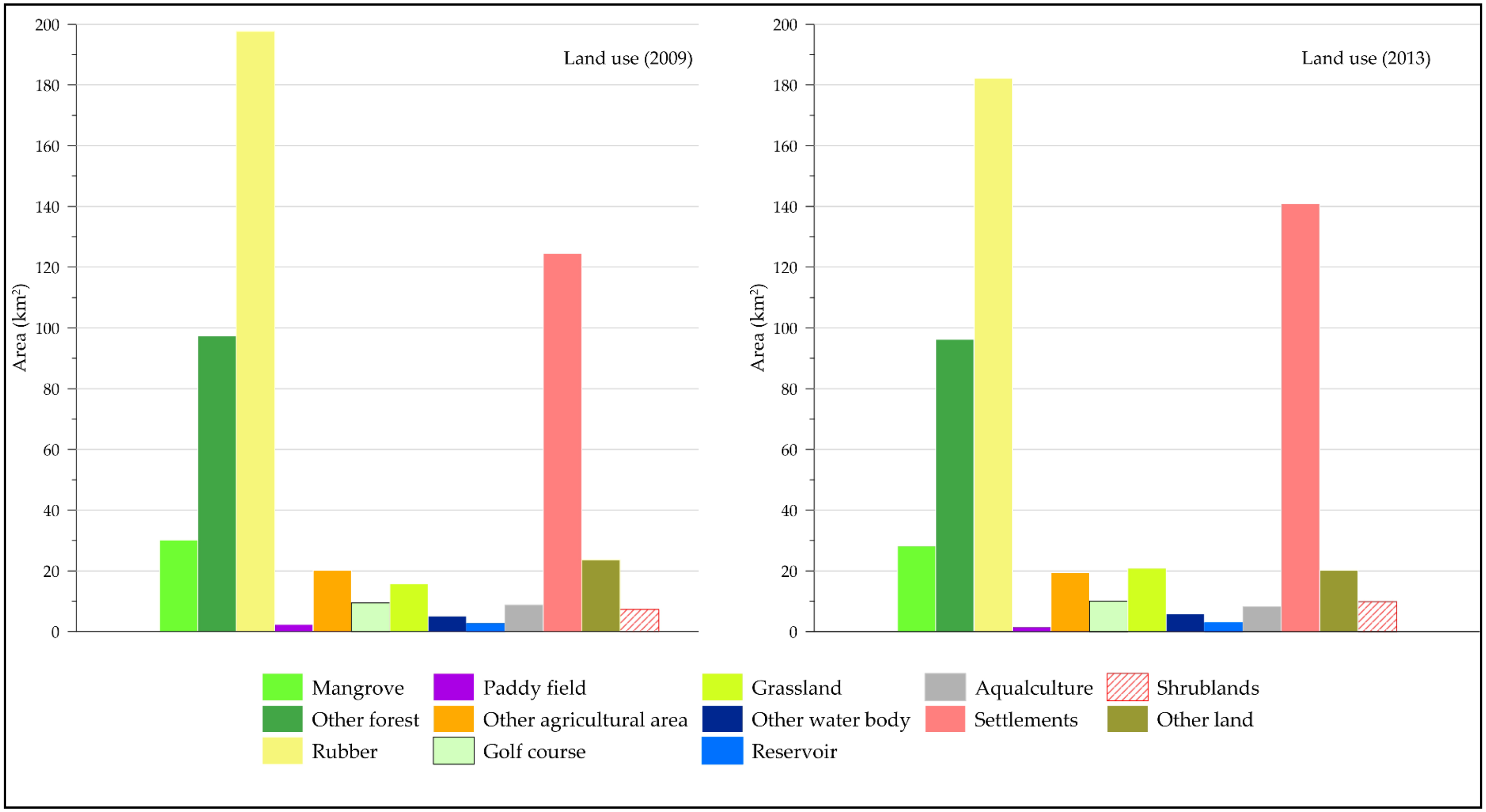

Figure A4.3 The area of land use in year 2009, and 2013

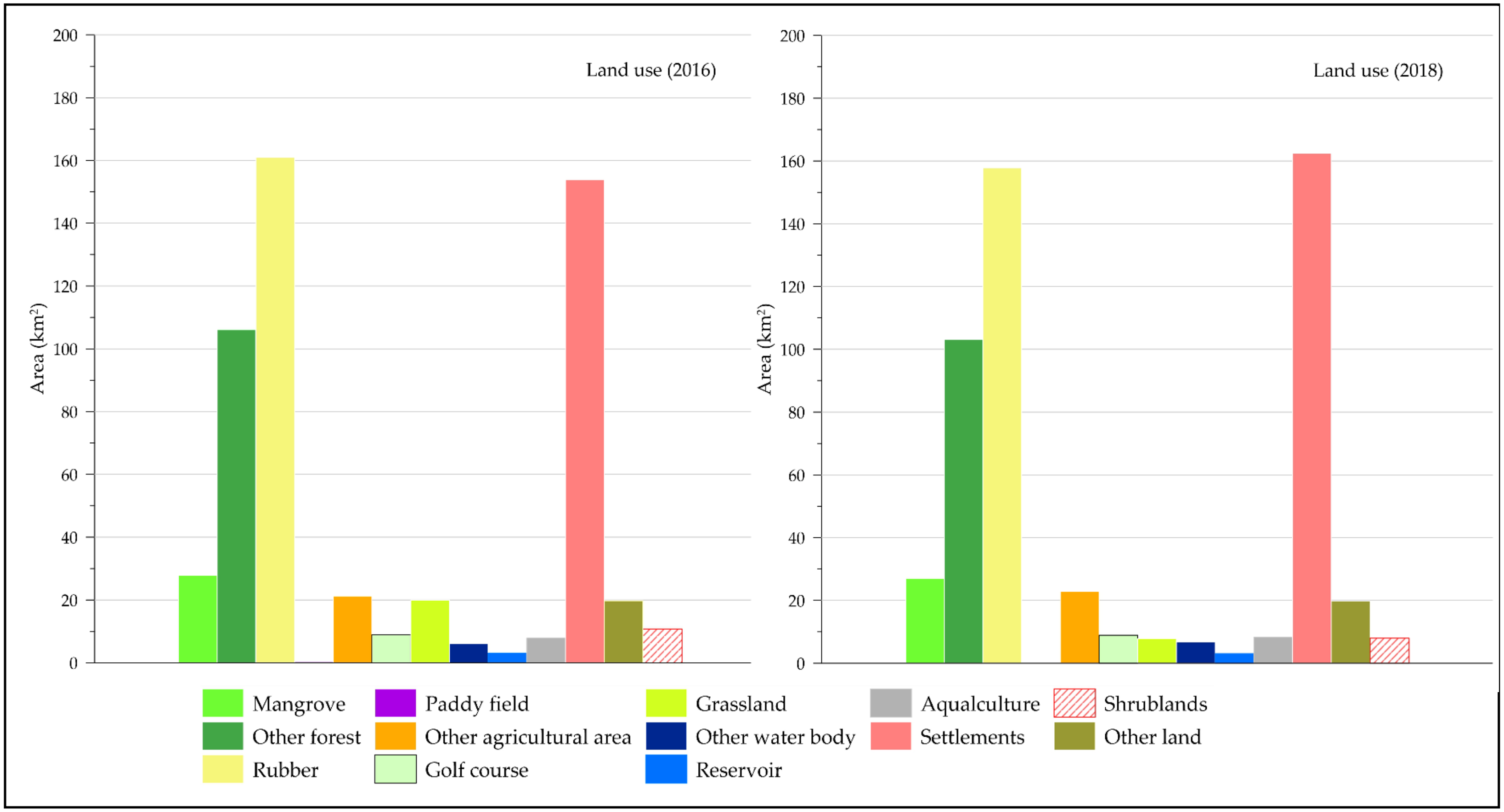

Figure A4.4 The area of land use in year 2016, and 2018

VITAE

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Educational attainment

Degree	Name of Institution	Year of Graduation
Bachelor of environmental science	Royal University of Phnom Penh	2014
Master of Science	Prince of Songkla University	2020

Scholarship awards during Enrolment

- The Scholarship Awards for master's degree under the project Thai Royal Princess Scholarship from May 2017 to July 2019