LAND USE CHANGE AND ITS IMPACTS ON WATER PUMPING IN BANG PAKONG RIVER BASIN, THAILAND

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Natural Resources Management

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ABSTRACT

There is an increasing need to plan water use in Thailand, due to increased water requirements from various sectors. The purpose of this study was to assess land use change and agricultural water requirements in Bang Pakong river basin, Thailand. It also investigated the data of public organizations and projected the trend of land and water in the future. Spatial tools and in-depth interviews were applied in this study. We used classified images from Landsat TM between 2002-2016. We calculated water requirements for irrigation of rice and and for production of fish and shrimp crops. We then built a main scenario for land changes and agricultural water requirements in the future.

Over the past 15 years, farming of perenial crops and aquaculture have been increasing while paddy field, field crop, and orchard have been decreasing. In terms of crop water requirement in the dry season, irrigated rice requires approximately 5,500 m3 per hectare while fish and shrimp farming requires 7,180 m3 per hectare. In a main business-as-usual scenario, rainfed rice will keep on decreasing while perennial crop will be increasing. Main changes in terms of water requirements will probably come from the non-agricultural sector in the future.

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AIT	Asian Institute of Technology
DEDP	Department of Energy Development and Promotion
DWR	Department of Water Resources
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GDP	Economy and a Gross Domestic Product
GIS	Geographic Information Systems
LDD	Land Development Department
OAE	Agricultural Extension Office
PWA	Provincial Waterworks Authority
RID	Royal Irrigation Department
THAICID	Thai National Committee on Irrigation and Drainage
TM	Thematic Mapper
USGS	United States Geological Survey

CHAPTER 1
INTRODUCTION

1.1 Background

Land Use Change on Water Resources

Population is rising and this leads to more land encroachment. Land use such as agriculture, forestry, urbanization, recreation, and industrialization impact on water resources. Agriculture, the draining of wetlands, tillage of the land and deforestation change infiltration and runoff characteristics, which affect groundwater recharge, sediment and water yield, and evapotranspiration.

More land uses, more removal of surface and ground water. For example, demand for water to irrigate crops usually occurs when there is insufficient precipitation during the growing season, potentially causing stream and groundwater levels to be reduced. In addition, irrigation waters that return to either groundwater or surface waters can contain salts, pesticides, or have elevated levels of nutrients such as nitrate and phosphorous (Vandas et al.,2002).

Water resources in Thailand

Thailand is situated in the Southeastern region of Asia. Thailand has four main regions; North, Central, Northeast and South regions. North region is generally mountainous which is the origin of four major rivers in Thailand which are Ping, Wang, Yom, and Nan rivers. Then flow to become to the Chao Phraya River at the Central region (FAO, 2011).

Thailand is the second economy of Southeast Asia with an open, export-orientated economy and a Gross Domestic Product (GDP) of 405 billion (2014). Thailand faces major challenges with regard to climate change and the availability of purified water. Demand for water in the country's main economic sectors, such as tourism, industry and agriculture, continues to increase, having a major impact on the country's fragile water infrastructure and resources. Waste water and sanitation infrastructure in Thailand is underdeveloped. There is an excessive discharge of industrial waste in rivers, causing water pollution and health problems. Recent floods and drought, water pollution and increasing demand for water showing the need for an integrated development of water resources and management in Thailand (Asia et al, 2014).

Water use in Thailand

Thailand has abundant water resources in total terms with an estimated 126 billion cubic meters (m3) per annum exploitable, considerably more than the reported national demand for water of some 50–56 billion/m3/annum . Seasonal variability results in droughts experienced by farmers and floods in urbanized areas. The droughts limit agricultural production, and the floods lead to loss of lives and massive economic losses, as in the 2011 major floods in the Chao Praya river basin, which resulted in lives lost and economic loss. Investments in water storage have been significant, but the sometimes-conflicting objectives of multipurpose reservoirs are often difficult to reconcile in operations, with devastating consequences. With growing opposition to the development of more dam sites, management of existing storage must be improved (ADB, 2016)

Water management in Thailand

With population increases and greater socioeconomic development, a more efficient and integrated approach to water resources management is needed to ensure more equitable and efficient use of water. The existing institutional framework for water resources management is highly fragmented, with about 30 departments and bureaus overseeing water management issues in some eight ministries. Policies, laws, regulations, and guidelines have been formulated within this context and are therefore not suitable for a more integrated approach. No national water resources legislation enables integrated water resources management. Initiatives for integrated water resources management (IWRM) were taken in the 1990s, but progress has been slow. The National Water Resources Committee was established, but it has no power to implement policy. In 2002 the Department of Water Resources was established as a regulator, and provided limited support to IWRM and operation of river basin committees (RBCs). The approximately 25 RBCs throughout the country are promising developments for grassroots participation in IWRM, but they are not legal entities and have poorly defined roles. While RBCs do attempt to allocate water within a basin, in the absence of a national water law, Thailand currently has no formal system of water rights (ADB, 2016).

Thailand does not have a water law. Drafts of a National Water Policy and a National Water Law have not been adopted due to a lack of shared vision and political will (ADB, 2016). Therefore, Thailand's legislative and institutional framework need to be strengthened. Although a Master Plan has been drafted, institutional competition and political issues prevent it from being implemented. The institutional framework is highly fragmented, lacking a single-commanded authority and an integrated approach, which leads to inconsistent strategies and budget allocation. The Thai government increased investment in its water sector and has announced new projects and funds to address the persisting risk of floods and drought, providing business opportunities (Asia et al, 2014).

The Water Act in Thailand is supposed to become the main legislative framework on water management. However, the act has been in the process of drafting since 1992. Again Department of Water Resources (DWR) is in charge of drafting the act. Currently, there is a new Water Act drafted in 2015 and until in 2017, the Act is still in the process of National Legislative Assembly. The improvement of this new Water Act is integrating water use with management, conservation, restoration and development water plans to enhance the unity in terms of preventing droughts and floods. Including of giving authorities to the public sector in order to access water resources which used to be only the government sector's authorities. And along with separating 3 levels of water uses which are national level, basin level and water user level to encourage more public participation in water resources management (DWR, 2015).

1.2 Statement of the Problems and Rational

The result of land use change, especially agricultural intensification, marginal lands have been turned into productive areas. Nowadays, Eastern region is one of the most water consumption of Thailand. In Bang Pakong river basin where urbanization and industrialization have been expanded due to Thailand Eastern Seaboard Development Policy. Deep sea ports are the target areas of this project, Chonburi and Ra Yong provinces are developed to support for industrial estate base, investment and the center of infrastructure in the Eastern region of Thailand. Those development expanded to Chacheongsao and Prachinburi province. More development, infrastructure lead to consume more water resources as well.

Agriculture sector is also one of the most consumption of water, especially with some agricultural activities that need to irrigate water. Irrigating water is limited based on priority of each sector. In Bang Pakong river basin, saline water is going up every year, it needs fresh water to flush out those saline water otherwise crops and things can be damaged. Crops that need to irrigate water normally face with lack of water in the dry season. If agriculture sector increase in the future, more water is needed as well.

Moreover, In terms of Water planning, Thailand has the national water vision statement "*By the year 2025, Thailand will have sufficient water of good quality for all users through efficient management and an organizational and legal system that will ensure equitable and sustainable use of the water resources, with due consideration given to the quality of life and the participation of all stakeholders"* (Le Huu Ti and Facon, 2001). This plan has to integrate with many water sectors, especially with local sectors. However, the main problems with water management in Thailand is that most laws that relevant to water resources are not updated. All existing laws on water resources are only concentrated on water management. There is a draft of Water Act that specifies water rights, river basin organizations and national apex body for water management. This Water Act draft passed the cabinet in June 2007 and it is waiting for approval from the parliament. Morover, the earlier versions of this law have been at this stage before but failed to pass (FAO, 2011).

As a consequence, improving more detail in water management in Thailand with the updated of water data can assess the change of water resources in Thailand. With this situation when population is growing continually, water demand is definitely increased and water quality will be deteriorated by many water sectors, assessing the water use with scenarios can be a possible way to manage the water resources in Thailand in the future.

In terms of water use, it is a crucial understanding for the study about water assessment as the word water use can be varied in different purposes, it is not only meant by the use of water in different activities but the water use is mainly separated into the water consumption and the water pumping. As the water consumption is the process of water that is depleted or consumed by human while the water pumping is when the water is pumped directly from its sources such as the rivers or streams. A proper understanding of water use can be useful to find out that the amount of water pumped, how much the water is consumed and how much the water return back into the system, to better manage more efficient of water use.

Therefore, the water pumping is needed to be concerned more because it can indicate the amount of water resources that are pumped from the sources and how can those amount of water pumping will be managed to use effectively. Moreover, the issue on water resources are especially occurred in the dry season [1] as more water is needed in this period and it is needed to manage the water for each water sector at this period of time.

In basin level, Bang Pakong river basin has an area around 18,000 km2 and is located in the eastern Thailand. It is one of Thailand's central basin where it discharges into the Gulf of Thailand (Molle, 2007). There are several water issues in Bang Pakong river basin include salinity, floods, water shortage and water competition between water users. Due to tidal influence from Chaopraya River, it leads brackish water to reach all the way upstream in dry season. Thus, saline water from sea intrusion regularly occurs in Bang Pakong basin which adversely impact on water users (KU, 2006). Not only salinity from sea water intrusion but flood is another issue in the basin. High levels of precipitation over a short period are cited as the most important factor responsible for triggering severe flooding in Bang Pakong river basin. Therefore, the Lower Bang Pakong sub-basin is a flood-prone area where some parts of it has experienced a flood every year over the last 3 years. (Seekao and Pharino, 2016). The basin serves as a water supply for drinking water, agriculture, aquaculture, and industry (Simachaya, 2003). As many sectors benefit from this basin, it leads to water demand increased. As a consequence, it occurs conflicts among different water users, especially between agriculture and other sectors during dry period. In addition, more water is demanded from all sectors including of using water resources for economic activities, Bang Pakong river basin as well as faces with water shortages during the dry period.

[1] The dry season in this study refers to the period between November – April when the level of rainfall is the least based on a climatic data of Thai Meteorological Department.

1.3 Objectives of the Research

1.3.1 General objective

Assess land use change and its impacts on water pumping in Bang Pakong river basin, Thailand.

1.3.2 Specific objectives

1. To assess land use change in Bang Pakong river basin between 2000 and 2016 using spatial application.
2. To assess water pumping by different water users in Bang Pakong river basin during the dry season.
3. To investigate the data collection method and the information by public institutions in terms of land use and water use in Bang Pakong river basin.
4. To project business as usual scenario trends in land use and water use in the Bang Pakong river basin by 2028.

1.4 Research questions

To assess land use change in Bang Pakong river basin between 2000 and 2016 using spatial application.

1. What are the dynamics of land use change in Bang Pakong river basin between 2000 and 2016?
2. What are the drivers of change in Bang Pakong river basin?

To assess water pumping by different water users in Bang Pakong river basin during the dry season.

1. How much water they pump during the dry season?
2. How much water requirement of crops in the dry season?

To investigate the data collection method and the information by public institutions in terms of land use and water use in Bang Pakong river basin.

1. What are the public organizations that in charge of land use and water use in the Bang Pakong river basin?
2. What are the issues of data in terms of land use and water use in Bang Pakong river basin?

To project a business as usual scenario in land use and water use in the Bang Pakong river basin by 2028, based on on-going trends.

1. What are the evolution of agricultural use and water use in Bang Pakong river basin by 2028?

Scope and Limitations

The scope of this study is limited to the geographical area of Bang Pakong river basin, Thailand.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction of River Basin

A river basin is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. River basins are important because the stream flow and the water quality of a river are affected by things and human-induced (USGS, 2016). Nowadays, the demand of water use is growing due to population increase and that have an impact on water resources as the water is more withdrawal from surface and groundwater. Water resources in the basins are used by several purposes by human until the water quality is degraded, the ecosystems in the river are threatened. Especially in increase demand of water leads to water use competition by many sectors from upstream until downstream such as industries, mining and to supply populations with drinking water (Molle, 2007).

2.2 River Basins in Thailand

The river basin in Thailand can be hydrologically divided into 25 river basins. The total volume of water resources from the rainfall of all river basins is averagely at 800,000 million m3. 75 percent or around 600,000 million m3 is lost through evaporation, evapotranspiration and infiltration and the remaining 25 per cent or 200,000 million m3 remain as the runoff that flows into the rivers and streams (THAICID, n.d.).

2.3 Research Methodology

Geographic Information Systems (GIS) is an effective tool for acquiring fast and accurate information about the Earth's resources and for providing a medium for the efficient flow of information. Moreover, these systems are particularly suitable for determining land use types and monitoring their variation through time (Kemal Sönmez N. et al., 2009). In terms of application of GIS in river basin management, most of the studies used GIS and Remote Sensing to assess land use changes. Satellite imagery from LANDSAT TM 5, 7 and along with spatial tools, especially GPS, topographic map, aerial photo, land use map and orthophoto map were used with supervised classification method in GIS (Wagner et al., 2013) The data from satellite imagery with ground-based survey information can monitor land use changes around river basin area and help to assess the water use scenarios in the future.

2.4 Land Use Changes on River Basins in Thailand

Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO, 2011). Land use changes is one issue on river basins area due to population growth and country development. For instance, expansion of infrastructure in the remote areas, industries and encroachment of people to settle and do crop cultivation. In Thailand, land use changes on River Basins is one of the serious problems nowadays. According to the study of Suchat Mulmuang (2003), Mae Raek basin was studied land use changes during the year 1988-1997 using GIS, satellite imagery from LANDSAT5, land use map and GPS to assess land use changes in the basin applying with land use classification and overlay method in GIS. This study found that agriculture area, especially shifting cultivation and residential area are increased while forest area is dramatically decreased to 35.38 percent. The results that the changing of forest area has been found in several studies (Ratanasuwan, 2001; Sihanantavong, 2004; Kaewjampa et al.,2008). They classified land use into mainly five types; forest area, agricultural area, urban and built-up area and water area. The changing of forest and water area into agriculture and urban is increased and tend to increase rapidly in the future.

2.5 Land Use Planning on Water Use in Thailand

Land use changes map is not only use for monitoring dynamics of land use in River basins, but also use to plan for water management. The study in Mae Chaem basin revealed that land use in Mae Chaem basin which can be classified into forest, agriculture, deserted orchard, shifting cultivation, urban and water area were classified by LANDSAT 5TM. They used the land use changes map to design the pattern of changes that influenced the amount of surface water in the Basin. The study found that from 22 patterns of land use, they were only 4 of it that were not influenced the quantity of surface river and this study used the most effective pattern to design the approaches for water use planning in the future, in this case, they have to minimize shifting area and recover deserted forest (Ratanasuwan, 2001).

The plausible scenarios of land use change can be evaluated by assessing impacts of land use change on water area. Using LANDSAT data can be possible to predict land use changes in the future for developing the plan for water use. Also, spatial tools, especially Satellite imagery and GIS can be helpful for detecting land use changes in the large area. Applying those tools with specific methodologies in GIS, especially overlay method can help identifying the drivers of land use changes. Thus, it is possible to design scenarios for the water use management in the future (Srihanantawong, 2004).

Homdee et al. (2011) investigate potential impacts of land use change on water in The Chi river basin in Thailand. The study designed five land use scenarios which are a change of forest area, farmland, conversion of paddy field to other crops and another two scenarios relevant to a conversion of farmland to rice and sugarcane crops. The results showed that different land use scenarios provided different annual and seasonal effects on water resources and evapotranspiration (ET). For example, the conversion of paddy field to farmland, there is small changes occured on annual flow and ET but the most significant effect occured on seasonal flows that lead to an increase of water yield up to 5.1% during the dry season.

2.6 Water pumping

It is needed to distinguish between water consumption and water pumping. Water pumping or water withdrawal refers to water diverted from its sources which is mainly from surface subsurface water or rivers and streams and is depleted for human use. Some part of the water is returned after pumped and can subsequently be reused or restored to the environment. The non-returned part represents consumed water, namely water that is evaporated or incorporated into products and organisms (Verdegem & Bosma, 2009).

One dimension of water use is water depletion. It is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. As several studied showed that the available water resources that can be used cannot directly measured or it is difficult to assess water use because it need to calculate water from its system- The Gross inflows until the outflows (Molden 1997; Molden et al. 1999; Sakthivadivel et al. 1997). Therefore, it is extremely important to distinguish water depletion from water diverted to a service or use, as not all water diverted to a use is depleted. Water is depleted by four generic processes:

1**. Evaporation**: water is vaporized from surfaces or transpired by plants.
2. **Flows to sinks**: water flows into a sea, saline groundwater or other location where it is not readily or economically recovered for reuse.
3. **Pollution:** water quality gets degraded to an extent where it is unfit for certain uses.
4. **Incorporation into a product**: through an industrial or agricultural process, such as bottling water or incorporation of water into plant tissues.

Water consumption or process consumption is one of the process of water depletion that is mostly processed by human. Water consumption is when human diverted that amount of water and depleted to produce an intended product such as industrial (cooling, cleaning), domestic (washing, drinking) and agricultural uses (transpiration) is referred to as process depletion.

Normally, some parts of outflow from the water-balance domain will be committed to meet other uses, such as downstream environmental requirements or downstream water rights, it is *committed water*. However, water pumping is unnatural process of using water. Due to shortage of water in many developing countries, for improving irrigation of water supplies, water has to be pumped to reduce the dependence on rain S.S. Chandel et al., (2017). Water that is not depleted or committed and is therefore available for a use within the domain, but flows out of the domain due to lack of storage or sufficient operational measures is called *uncommitted outflow*. It is utilizable within the irrigation system or elsewhere (Molden et al., 2001).

Water accounting based on water balanced approach of Renault et al., (2001) is another example that applied a classical approach of water for monitoring and measuring depleted water from specific purpose to demonstrated a conflict between the amount of available water pumping and a truly water consumption by crops. The main findings showed that at the Kirindi Oya project, Sri Lanka perennial vegetation is a significant factor in the use of water resources (43%), while only 22% of the available water is really consumed by crops. Improving water productivity is a priority for many decision makers and managers, and a reliable water balance is the ground on which strategies for improvements have to be built. This water balance study demonstrated that evaluations based on classical notions of efficiency are inadequate. A better approach is to calculate the rate of beneficial utilization which is the ratio of consumption by beneficial uses to the amount of water available for use in the irrigated area.

2.7 Water consumption for agriculture

In terms of assessment of water use for agriculture, one method can be applied to use which is ETo calculation (Evapotranspiration rate). ETo calculation can assess the water consumption of crop plants by considering Crop Coefficient (Kc) of Penman- Monteith and Potential Evapotranspiration (ETp)

$$ETo = Kc * ETp$$

ETo= Water consumption of crop plant (mm./day)
Kc = Crop Coefficient
ETp = Potential Evapotranspiration (mm./day)

For calculating Kc (Crop Coefficient), Penman- Monteith formula will be conducted in this study. Kc will be dependent on ETp (Potential Evapotranspiration) rate, species of crop plant and the growth rate of plants (HAII, 2012).

The meteorological data, provided by the Thailand Meteorological Department (TMD), will be selected from meteorological stations in the Bang Pakong river basin areas. These data will be used in estimating reference crop evapotranspiration by the FAO Penman-Monteith method (Kositsakulchai and Borne, 2004)

2.8 Water consumption of rice farming in Chao Phraya river basin

Thailand has two annual rice-growing periods, the wet-season (Khao na pee) and the dry-season (Khao na prung). The wet- season rice harvest is the larger of two annual crops, normally accounting for roughly 70 percent of total annual production. Khao na pee is heavily dependent on monsoonal weather systems, with 70 percent of the crop being totally rainfed. The remaining 30 percent lies primarily in the western Chao Phraya river basin and is irrigated from water stored in mountain reservoirs. Khao na prung area averages 2.0 million hectares, is approximately 80 percent irrigated, and accounts for roughly 30 percent of total annual rice production. Khao na prung cultivation is heavily focused on irrigated farmland in the Lower North and Central Plains regions (USDA, 2017).

According to the report of Thailand Ministry of Agriculture and Cooperatives (2015) the amount of water consumption for rice farming, especially the second rice crop or *Khao na prung* in Chao Phraya river basin requires water around 5,123.76 MCM throughout the crop season.

Table 2.1 : The amount of water consumption of Khao na prung
Source : Office of Agricultural Economics, 2015 .

Area of Khao na prung (million ha)	The water consumption per rai (m3)	Total amount of water consumption (mcm)
0.71	1,154	5,123.76

Based on the water consumption of Khao na prung of 2015/2016 crop season, Chao Phra ya river basin required water more than an expected volume of water which have been planned to use only 177 mcm for agriculture. As a consequence, it will be impacted with the water that reserves for flushing saline water and maintenance an ecosystem.

2.9 Water consumption of shrimp farming in Chao Phraya river basin

The Chao Phraya river delta is one of the most important agricultural regions in Thailand. This delta represents a major production for shrimp farming, especially Black Tiger shrimp (Penaeus Monodon). However, in Thailand, inland shrimp farming evolved within traditional rice growing areas because raising shrimp requires a large quantity of brackish water to fill the pond and maintain environmental conditions during the grow-out period.

For that large amount of water, the proportion of water use for aquaculture requires more water than manufacturing or industrial process. As a result, one issue of shrimp farming in Chao Phraya basin is water use conflict, especially in dry season when a natural water supplies are far more limited and freshwater consumption for shrimp farming could potentially affect aquatic habitats and produce water conflicts with other agricultural, industrial or domestic water users. A combination of freshwater from irrigation canals and hyper-saline water transported to the farm-site by truck is the preferred water supply for most low salinity shrimp farms in the Chao Phraya Delta during the dry season (Szuster and Molle , 2003)

CHAPTER 3
METHODOLOGY

3.1 Study area

This part will describe the study area in this study, the Bang Pakong River basin (Fig3.1). The Eastern regional context where the Bang Pakong River basin is located, and impacts of water management will also be discussed.

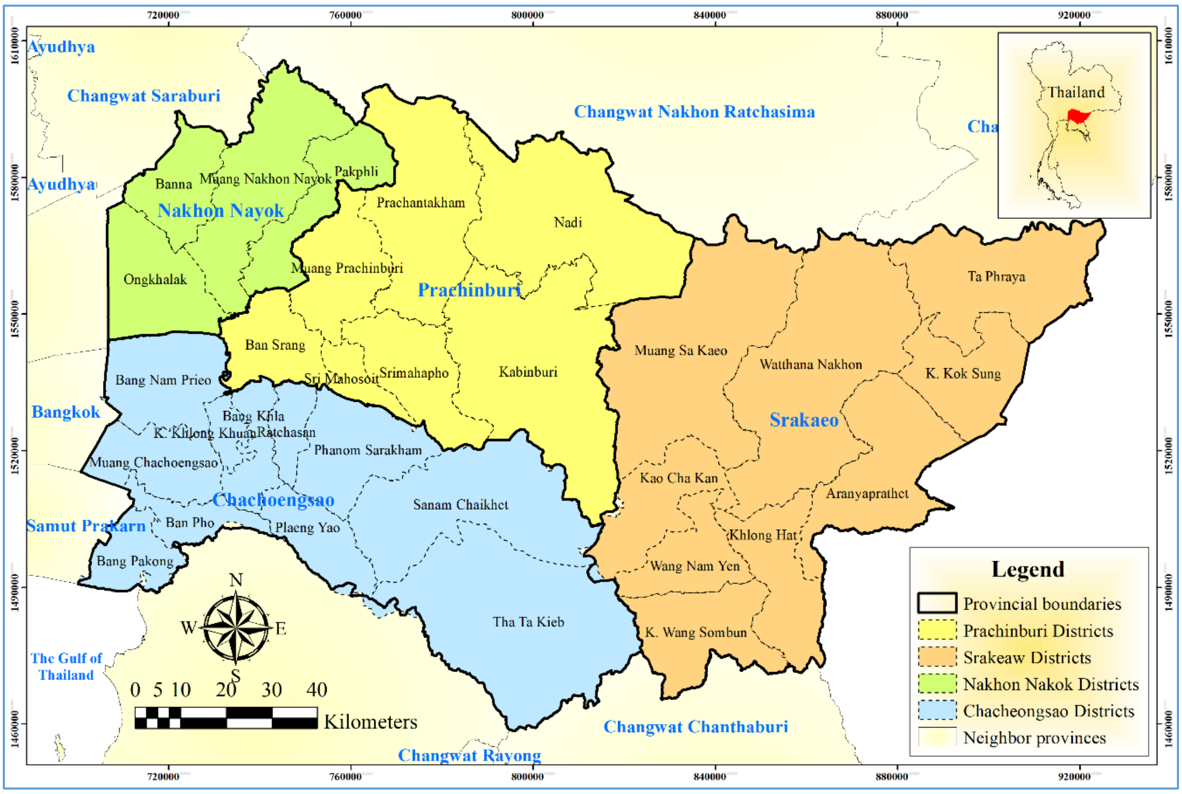

Figure 3.1: Bang Pakong river basin boundaries (own design)

3.1.1 Background of the study area

The Bang Pakong River basin has an area around 18,000 km2 and discharges into the Gulf of Thailand (Molle, 2007). The Bang Pakong river basin is located in the eastern region of Thailand. The Basin covers 4 provinces namely Nakhon Nayok, Chachoengsao, Prachinburi and Sakaeo provinces. The topology of the basin is mainly separated into hills in the north and northeast, flat in the south and east, some plains for agricultural purposes nearby the river. The major rivers in the basin are Bang Pakong river, Prachinburi river, Hanuman river and Klong Tha lat. The land use in the basin are agricultural land (crops, livestock and aquaculture), urban and industries. The densest of population is Chacheongsao Province (133 cap/km2) (Kupkanchanakul et al., 2015)

The Figure 3.2 shows the areas of the whole basin which in this study select Bang Pakong basin and Prachinburi basin. The Bang Pakong basin has a water capacity approximately 829.5 million cubic metre (mcm) while Prachinburi basin has 509.4 mcm (RID, 2017). The Bang Pakong basin consists of three sub-basins: Nakhon Nayok, Thalat and Main Prachin buri basin while the Prachin buri river basin comprises of four sub-basins: Khlong Phra Sathung, Khlong Phra Prong, Mae Nam Hanuman, and Main Bang Pakong sub-basin (KU, 2006). As shown in Figure 3.2.

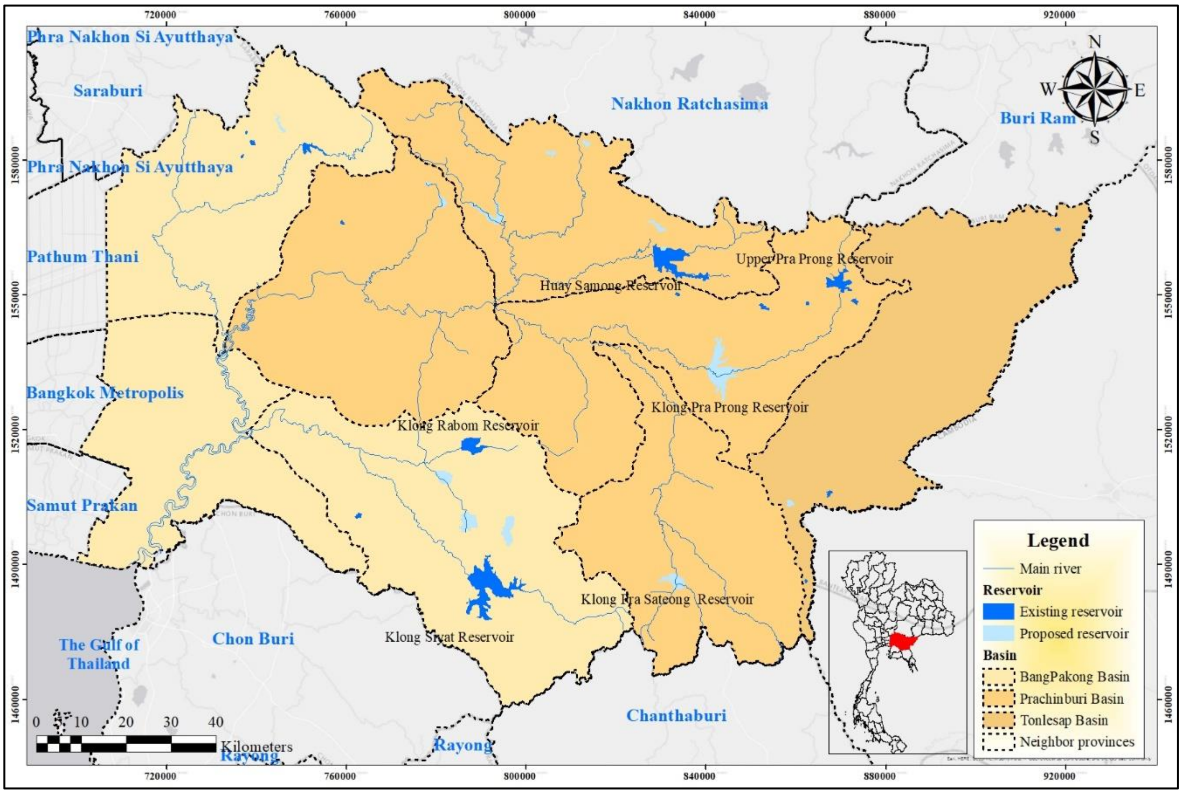

Figure 3.2: The Bang Pakong river basin and reservoirs (own design)

Due to its discharge, tidal influence is pronounced, with brackish water reaching 170 km upstream during the dry season when freshwater runoff is minimal (KU, 2006). Rainfall varies – by and large – between 1000 and 2000 mm and most of the runoff (8.6 billion m3 or Bm3) is generated in the Northern subbasins (Nakhon Nayok, main Bang Pakong, Hanuman (60%) and only 10% of runoff occurs in the dry season (Molle, 2007).

Table3. 1: The amount of water pumping in each water sector in Bang Pakong river basin Source : Hydro and Agro Informatics Institute (HAII), 2012

Water consumption purposes in Bang Pakong river basin	The amount of water pumping (Million Cubic Metre/Year)
1. Irrigation	2,718.77
2. Domestic use	70.33
3. Industry	18.70
4. Livestock	5.10
5.Aquaculture	673.87
6. Tourism	1.49
7.Maintenance downstream ecology and flushing saline water[2]	-
Total of water pumping	3,488.26

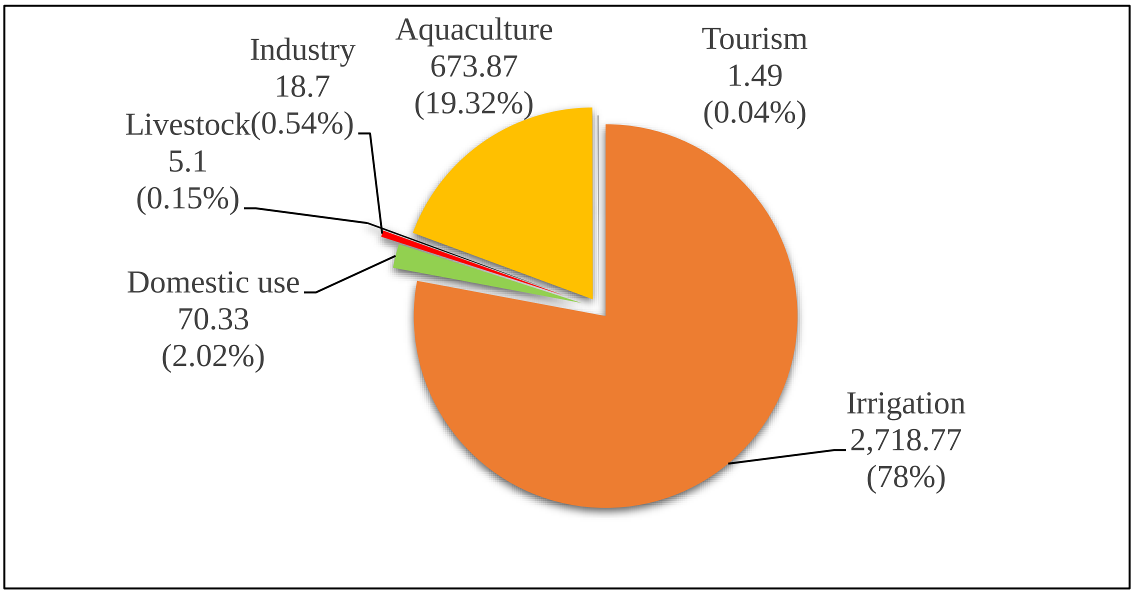

Figure 3.3 : The percentage of water pumping in each water sector in Bang Pakong river basin **Source :** Hydro and Agro Informatics Institute (HAII), 2012

The table 3.1 shows the amount of water pumping in each water sector in Bang Pakong river basin. Irrigation and aquaculture activities are the most pumping water sector in the basin around 2,718.77 m3 and 673.87 m3 per year. The Figure 3.3 above also shows the percentage proportion of each water sector in the basin. 6 purposes of water consumption are used in the basin.

As in Bang Pakong river basin composes with the 3 major basins which are Bang Pakong basin and Prachinburi basin. The table 3.2 below indicate the amount of water consumption by different purposes separately in each basin. It is clearly be seen from the table that Bang Pakong river basin is consumed more water resources than Prachinburi river basin as the nearby area of Bang Pakong river basin is a residential and agricultural area.

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2 The total amount of water pumping is excluded in the purpose of maintenance downstream ecology and flushing saline water depending on different water management.

Table 3.2 : The water pumping of the main the sub-basin in Bang Pakong river basin in 2001
Source : Hydro and Agro Informatics Institute (HAII), 2012

Main river basin/Sub-basin	Water pumping in 2001 (MCM/Year)							
	Irrigation	Domestic Use	Industry	Livestock	Aquaculture	Tourism	Total	Total (%)
Bang Pakong river basin								
Nakhon-Nayok sub-basin	663.85	8.59	1.42	0.22	93.61	0.10	767.80	22%
Talad sub-basin	339.76	5.41	0.36	1.43	9.43	0.00	356.39	10%
Main Bang Pakong sub-basin	1,097.79	16.41	3.56	3.00	239.71	0.92	1,361.40	39%
Klong Luang sub-basin	0.00	0.00	0.00	0.00	0.51	0.00	0.51	0%
Total	**2,101.40**	**30.41**	**5.34**	**4.65**	**343.27**	**1.02**	**2,486.10**	**71%**
Prachin Buri river basin								
Prasatueng sub-basin	26.80	7.83	0.24	0.02	0.00	0.00	34.90	1%
Praprong sub-basin	81.02	4.33	0.27	0.07	0.00	0.00	85.68	2%
Hanuman sub-basin	13.68	3.56	1.93	0.04	0.00	0.00	19.21	1%
Main Prachin buri sub-basin	**375.78**	**13.27**	**8.36**	**0.28**	**105.07**	**0.20**	**502.96**	**14%**
Total	**497.28**	**28.99**	**10.80**	**0.41**	**105.07**	**0.20**	**642.76**	**18%**
Total of all basins	**2,580.68**	**59.4**	**16.14**	**5.06**	**448.34**	**1.22**	**3,128.86**	**100%**
Total of all basins (%)	**82.47%**	**1.89%**	**0.51%**	**0.16%**	**14.32%**	**0.03**	**100%**	

3.1.2 The reservoir in the basins

The basins (Bang Pakog and Prachin buri basins) cover 4 provinces in the Mid Central of Thailand which are Nakhon Nayok, Chachoengsao, Prachinburi and Sa Kaew provinces. In each province, there is several reservoir projects in order to store the water to use in many sectors (Irrigation or agricultural purposes, domestic use and industries). The reservoirs include all small scale, middle scale and large scale depending on the capacity of the reservoirs.

According to the data of reservoir from Regional Irrigation Office 9th, the statistics of the amount of water in the reservoirs in Sa Kaew province shows that Sa Kaew province has 16 reservoirs and in February 2017, the overall capacity is 266.7 mmc, the amount of water is 125.4 mmc or 47% compared to the last year in 2016, 73 mmc or 27.4%. The largest reservoirs which have the water capacity more than 60 mmc in February 2017 are Huay Yang reservoir (60 mmc), Phra Phrong reservoir (97 mmc) and Klong Phra Satheung reservoir (65 mmc).

In prachinburi Province, the overall capacity in 2017 is 311.7 mmc while in the year 2016, the overall capacity was only 16.2 mmc. The amount of water in February 2017 is 230.8 mmc or 74.1% compared to the last year in 2016, 13.9 mmc or 86.1%. The largest reservoir in Prachinburi province which stores the water 295 mmc in 2017 is Narubadin Jinda reservoir.

In Nakhon Nayok Province, the overall capacity in 2017 is 250.2 mmc. The amount of water in February 2017 is 149.7 mmc or 59.8% compared to the last year in 2016, 126.8 mmc or 50.7%. The largest reservoir in Nakhon Nayok province which stores the water 224 mmc in 2017 is Khundan Prakanchon reservoir.

In Chachoengsao Province, the overall capacity in 2017 is 481.1 mmc. The amount of water in February 2017 is 174.4 mmc or 36.3% compared to the last year in 2016, 158.8 mmc or 33%. The largest reservoir in Chachoengsao province which stores the water 420 mmc in 2017 is Khlong Siyat reservoir.

As shown in the **Table 3.3,** the table summarizes all the capacity of all reservoirs in each provinces in the basin, Sa Kaew province has 16 reservoirs, more than other provinces following with Nakhon Nayok, Prachinburi and Chacheongsao province. As it can be seen in the table, the medium to large reservoir projects in the basin are mainly in Sa Kaew and Nakhon Nayok.

Table 3.3 The number and the capacity of reservoirs in each province in the basins
Source : Regional Irrigation Office 9th (2017)

Province	The number of reservoirs	The capacity of reservoirs			
		< 30%	30-50%	50-80%	>80%
Sa Kaew	16	4	3	7	2
Prachinburi	5	-	-	4	1
Nakhon Nayok	8	-	-	7	1
Chachoengsao	5	-	2	3	-

Based on the reservoirs in the basin, Royal Irrigation Office 9th have an annual plan on water resources in the province in the Eastern region as shown in the Table 3.4**,** this plan was designed in February 2017 to design the amount of water needs for 5 different water purposes: water supply, domestic use, agriculture, industries and ecological maintenance in each province based on its reservoirs in the province. However, it is needed to concern about the characteristic of each province before they plan. For example, Chacheongsao province has a lot of agriculture activities. Thus, they plan to allocate quite a large amount of agriculture purpose to Chacheongsao province.

Table 3.4 Water allocation plan in each province in the basins
Source : Regional Irrigation Office 9th (2017)

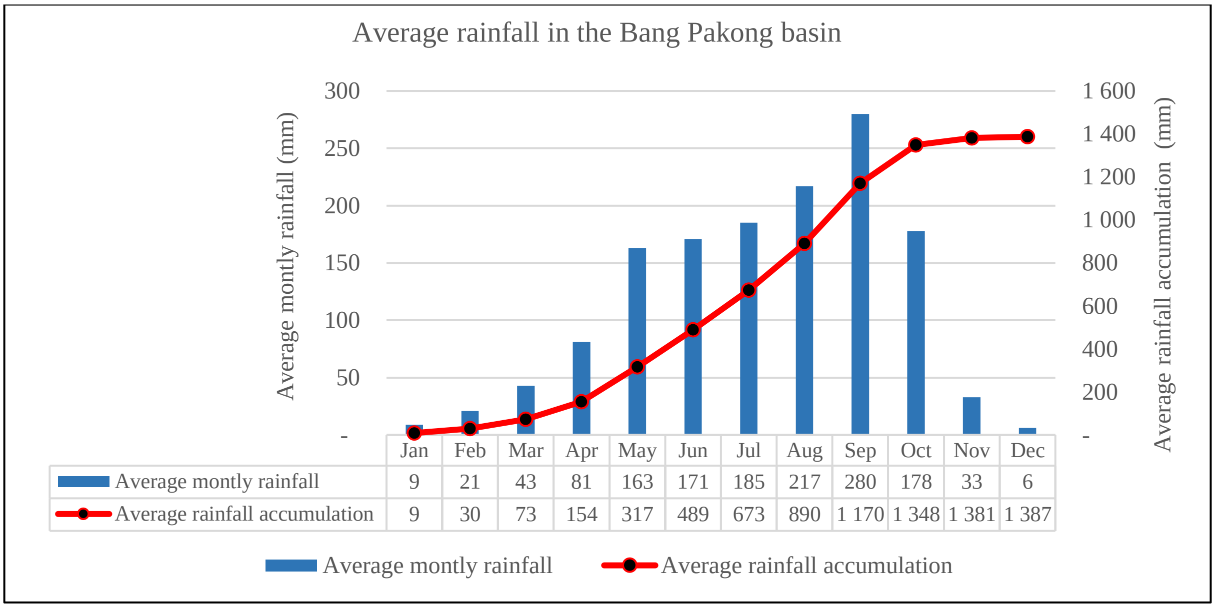
Province	The number of reservoir	Runoff + water diversion (mcm)	Capacity (mmc)	Water allocation plan (mcm)						
				Water supply	Domestic use	Agriculture	Industries	EAST WATER	Ecological+ Evaporation	total
Chachoengsao	**5**	**345.8**	**481.1**	**35.0**	**12.4**	**189.7**	**3.7**		**93.0**	**333.8**
Sa Kaew	**16**	**175.3**	**266.7**	**2.3**	**1.5**	**66.7**			**18.2**	**88.7**
prachinburi	**5**	**53.4**	**311.2**	**2.0**	**4.2**	**5.7**			**2.9**	**14.8**
Nakhon Nayok	**8**	**328.8**	**250.2**	**4.4**	**11.7**	**171.7**			**54.5**	**242.3**
Total	**34**	**903.3**	**1309.2**	**43.7**	**29.8**	**433.8**	**3.7**		**168.6**	**679.6**

3.1.3 Rainfall

The record of monthly rainfall from Thai meteorological department showed that during 20 years period between 1954 - 2005, the average annual rain is approximately 1,517 mm. The rainfall distribution is between May-September which the amount of rainfall is pretty high. While in November until April, the amount of rainfall is quite less.

Table 3.5 : The average yearly between 1954 – 2005 of surface water of each sub-basin in Bang Pakong river basin during rainy and dry season.
Source : DWR, 2008

Sub-basin	Sub-basin Code	Average rainfall (mm)		
		Rainy season	Dry season	Throughout the year
Main Prachin Buri				
Phra Sateung	15-02	1,073.0	173.6	1,246.6
Phra Prong	15-03	1,249.4	221.9	1,471.3
Hanuman	15-04	1,699.1	216.9	1,916.0
Main Prachinburi	15-05	1,541.0	145.5	1,686.5
Main Bang Pakong				
Nakhon Nayok	16-02	1,522.8	162.3	1,685.1
Tha lat	16-03	1,107.7	176.3	1,283.9
Main Bang Pakong	16-05	1,003.4	146.8	1,150.3



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average montly rainfall	9	21	43	81	163	171	185	217	280	178	33	6
Average rainfall accumulation	9	30	73	154	317	489	673	890	1 170	1 348	1 381	1 387

Figure 3.4 Average rainfall in the Bang Pakong basin
Source: HAII, 2012

According to a monthly rainfall from 35 Hydromet monitoring stations collected in the past 20 years (1954-2005). An average annual rainfall in the whole Bang Pakong basin is 1,347 mm. A distribution of rainfall is between May-October while November-April, the amount of rainfall is quite low. As a rainfall is low in such period, in the dry season, the water source from rainfall is insufficiency in the river basin, especially for several crops such as dry season rice, aquaculture and some others rainfed crops. Thus, irrigated areas are essential in the dry season.

3.1.4 Current Situation in the study area

- **Water use**

The Main water supply depends on the storage of water from large and medium-scale water resources development projects. Both are either constructed or undergoing construction by the RID, and the Department of Energy Development and Promotion (DEDP) while groundwater has a limited potential and is used only for a small percent of domestic, small-scaled industry, and for some other specific purposes. (Purotaganon, 2013). There are many sectors who benefits from this water that are fish and shrimp farmers, rice farmers, domestic users and industries sectors. As a result, it increases demand of water use, especially in dry season (November - April) when the water level is low due to lack of rainfall.

- Water quality

Brackish water is another water problem in Bang Pakong River basin. Brackish water intrudes up to 30 kilometers from the mouth of the river. The furthest distance on record where the salinity penetrated was 210 kilometers in 1998. (Purotaganon, 2013). Brackish water from the tidal Chaopraya river reaching all the way upstream during the dry season. Thus, it leads to high fluctuation of the saline water from sea intrusion, especially in June and November also with the geographical area is a flat plain. Therefore, brackish water intrude easily in the area and adversely effects with water users in crop cultivation and domestic users.

3.2 Data collection Method

This part is organized into two different sections: Data needs and data collection. Data needs explain about sources of data, primary and secondary expected to collect. Data Collection gives an explanation of the tools, methods and application of research methods and approaches to gain information from key informants involved in the study.

3.2.1 Data needs

- Primary data will collect from field survey in ground verification of land use classification to check an accuracy assessment of classified image from Land Development Department (LDD). Another primary data will conduct from an in-depth interview with public organizaions which are relevant to in charge of land use and water use such as Royal Irrigation Department, Office of Fisheries, Provincial Water Authorities and Provincial Agricultural Office.

- Secondary data will conduct from relevant public organizations which work in terms of land use and water use such as Land Use Classification from Land Development Department, reports, list of registered industries, statistical and data of water use in terms of agriculture, the registered crop cultivation of agricultural crops in order to assess the water consumption in the Bang Pakong river basin.

3.2.2 Data collection

- Key informants interview

The in-depth interviews will conduct from relevant public organizations which are categorized into 2 groups; one in charge of land use and another in charge of water use

Table 3.6 : List of public organizations for the key informant interview

Land use	Water use
1. Prachinburi Agricultural Extension Office (OAE)	1. Bang Phluang Irrigation Office
2. Prachinburi Industries Office	2. Prachinburi Fisheries Office
3. 6Th Regional Office of Agricultural Economics	3.Prachinburi Provincial Waterworks Authority (PWA)
4. Prachinburi Fisheries Office	4. Regional Irrigation Office 9th

Table 3.7: Bang Pakong River basin primary and secondary data

No.	Sources of data	Primary data	Secondary data
1.	Land Development Department (LDD)	-	-Land Use Changes classified image in 2002-2016 in Bang Pakong river basin. - Administrative boundaries (shapefile).
2.	Department of Water Resources (DWR)	-	- Draft water act 2017 - Previous assessments of water uses.
3.	Field survey/Ground check	- Random points map.	-Random points in Google Earth Engine.
4.	Royal Irrigation Department (RID)	- In-depth interview with the head of RID.	-Plan for Water Resources Development in Prachinburi. - Statistics on water use of each water sector. - Data on Evapotranspiration of plants (Kc, Eto).
5.	Office of Industries	-In-depth interview with the officer from the Office of Industries in Prachinburi province.	- Registered water use licenses on industries. - The list of industries in the province.
6.	Department of Fisheries	- In-depth interview with the head of Prachinburi Fisheries Office.	- Statistics and report of aquaculture crops. - Report on water use of aquaculture crops
7.	Office of Agricultural Extension	- In-depth interview with the officer from Agricultural Extension Office in Prachinburi province.	- The report/data of economic crops in the basin scale.
8.	Regional Irrigation Office 9th	- In-depth interview with the head of RID.	- Statistics on water pumping on every sector in the basin scale. - Shapefile on irrigation zone.
9.	Bang Phluang Irrigation Office	- In-depth interview with the head of Irrigation Office.	- Map of irrigation zone in Prachinburi province.
10.	Prachinburi Provincial Waterworks Authority (PWA)	- In-depth interview with the managers of PWA in Prachinburi province.	- The data on water consumption for drinking water sector.
11.	The Geo-Informatics and Space Technology Development Agency (GISTDA)	-	- Shapefile of dry season rice in the basin level from 2014-2017.

3.2.3 Data Analysis

Methodology Objective 1: To assess land use change in Bang Pakong river basin between 2000 and 2016 using spatial application.

Table 3.8: Analytical framework of the research objective 1

Objective 1	Research questions	Data collection	Outputs
-To assess land use change in Bang Pakong river basin between 2000 and 2016 using spatial application.	1. What are the dynamics of land use change in Bang Pakong river basin between 2000 and 2016? 2. What are the drivers of change in Bang Pakong river basin?	**Primary data** - Ground verification in Bang Pakong river basin with satellite imagery of study area. **Secondary Data** - Land Use Classification in Bang Pakong river basin from Land Development Department (LDD) in 2002, 2006, 2009, 2013, 2016 classifying in level 1 and 2. - Administrative boundaries shapefile from Land Development Department (Tambon level)	1. Map of land use changes classified into 5 types: Agriculture, Forest, Water, Urban and Miscellaneous land in Bang Pakong river basin in the past 14 years (2002, 2006, 2009, 2013, 2016). 2. Map of Agricultural land classified into the main types of agriculture (Paddy, Perennial, Orchard, Field crop and Aquaculture land) in the past 14 years (2002, 2006, 2009, 2013, 2016). 3. Tables and graphs of the area dedicated to each land use in the past 14 years.

3.3 Data Preparation

In this objective, this study will use secondary data about land use classification data from Land Development Department (LDD) of four provinces (Nakhon Nayok, Chachoengsao, Prachin Buri and Sa Kaeo province where it covers all Bang Pakong river basin boundaries. The shapefile will be used in 2002, 2006, 2009, 2013 and 2016 that will be in 14 years periods. Moreover, ground verification is necessary for accuracy assessment.

Land use change was detected for five time periods by using data from 2002, 2006, 2009, 2013 and 2016. In 2016, was the most current land use data available at the time of the study. Land use change maps for the years 2002, 2006, 2009, 2013 and 2016 were obtained from the Land Development Department of Thailand (LDD) in digital format (Arcgis shape file) on request. The land use maps were interpreted from Landsat-5, Landsat-8 Thematic Mapper (TM) and Theos satellite data. Classified using the Land Cover Classification System (LCCS) at the scale of 1:25,000 and projected into a UTM zone 47N and UTM zone 48N using a WGS1984 or World Geodetic System 1984 for consistency. The land use classes were regrouped for all the Bang Pakong river basin area where the total area is approximately 1,913,436.33 hectare into 5 major land uses classes which are agriculture land, forest land, miscellaneous land, urban land and water body.

Tools and equipment

1. Camera
2. Global Positioning System (GPS)
3. Arcgis Software
4. Google Earth Engine

Image Classification

According to GISTDA (2013), Land Cover Classification is a defined system for classifying the types of land uses in order to analyze and interpret the data from remote sensing along with ground survey. In Thailand, land use and land cover classification is based on Land Development Department which use from Fundamental Geographic Data Set (FGDS) standard. FGDS is designed under the country's scale by Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand.

Basically, FGDS is an Imagery Base Maps of Earth Cover. FGDS is one dataset related to land use data which is categorized into 3 hierarchical levels (level1, level2 and level3) by analyzing and interpreting data from satellite imagery or aerial photography with ground survey. After that, the data will be transformed by digitization process. FGDS will be classified land use types into mainly 5 types and also used an abbreviation to code its name.

Table 3.9 : The meaning of Land use types from FGDS standard
Source: IDD, 2012

Code	**Meaning**
1. U	Urban and Built-up land
2. A	Agricultural land
3. F	Forest land
4. W	Water body
5. M	Miscellaneous land

Identifying land use types in this FGDS standard, it will be classified by its own characteristics of land use. It is needed to follow from the definition of land form by its geographical characteristics. FGDS will be explained in terms of both spatial and attribute data in different levels according to the quality of the images. Finally, the land use data will be collected in form of vector map or digital map. In first level, it has the lowest resolution, or detail of the landscape, while level two has higher resolution and level three has the highest resolution. For example,

Table 3.10 : One example of sub-categorization of Agricultural Land (own design)

Code	Level I	Level II	Level III
A	Agricultural land	**A9** Aquaculture	**A902** Fish farm **A903** shrimp farm

Table 3.11 : **Land Use and Land Cover Classification in Bang Pakong River Basin based on Land Development Department (Own design).**

Level 1	Level 2	Level 3
U Urban and built-up area	**U1** City, town, commercial **U2** Village **U3** Institutional land **U4** Communication and utility **U5** Industrial land. **U6** Other	-
A Agricultural area	**A1** Paddy field **A2** Field crop **A3** Perennial **A4** Orchard **A5** Horticulture **A6** Swidden cultivation **A7** Pasture and farm house **A8** Aquatic plant **A9** Aquacultural land	**A101** Rice paddy **A204** Cassava **A414** Guava **A902** Fish farm **A903** Shrimp farm
F Forest area	-	-
W Water body area	**W1** Natural water body **W2** Built-up (reservoir)	**W101** River canal **W201** Reservoir **W202** Farm pond.
M Miscellaneous land	**M1** Rangeland **M2** Marsh and Swamp **M3** Mine, pit **M4** Others	**-**

3.4 Accuracy Assessment

Assessment of classification accuracy of 2016 images will be carried out to determine the quality of information derived from the data. For the accuracy assessment of land use changes in Bang Pakong river basin map, stratified random method will be used to represent different land cover classes of the area. The accuracy assessment will be carried out using 260 points. After that, it will be rechecked based on ground truth data and visual interpretation to ensure verification of the accuracy of image interpretation.

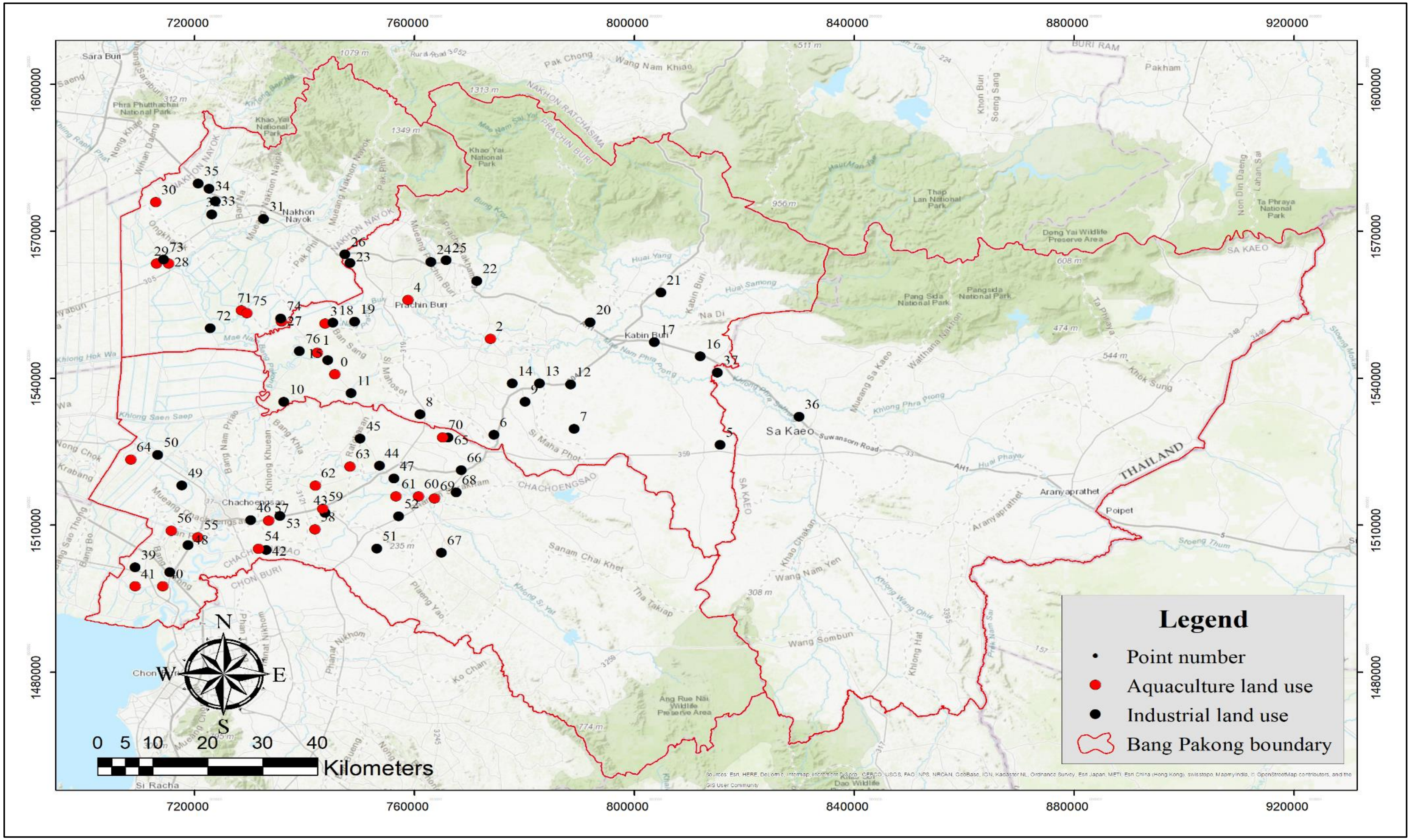


Figure 3.5 Ground check points position for aquaculture land and industrial land classification accuracy assessment (2017).

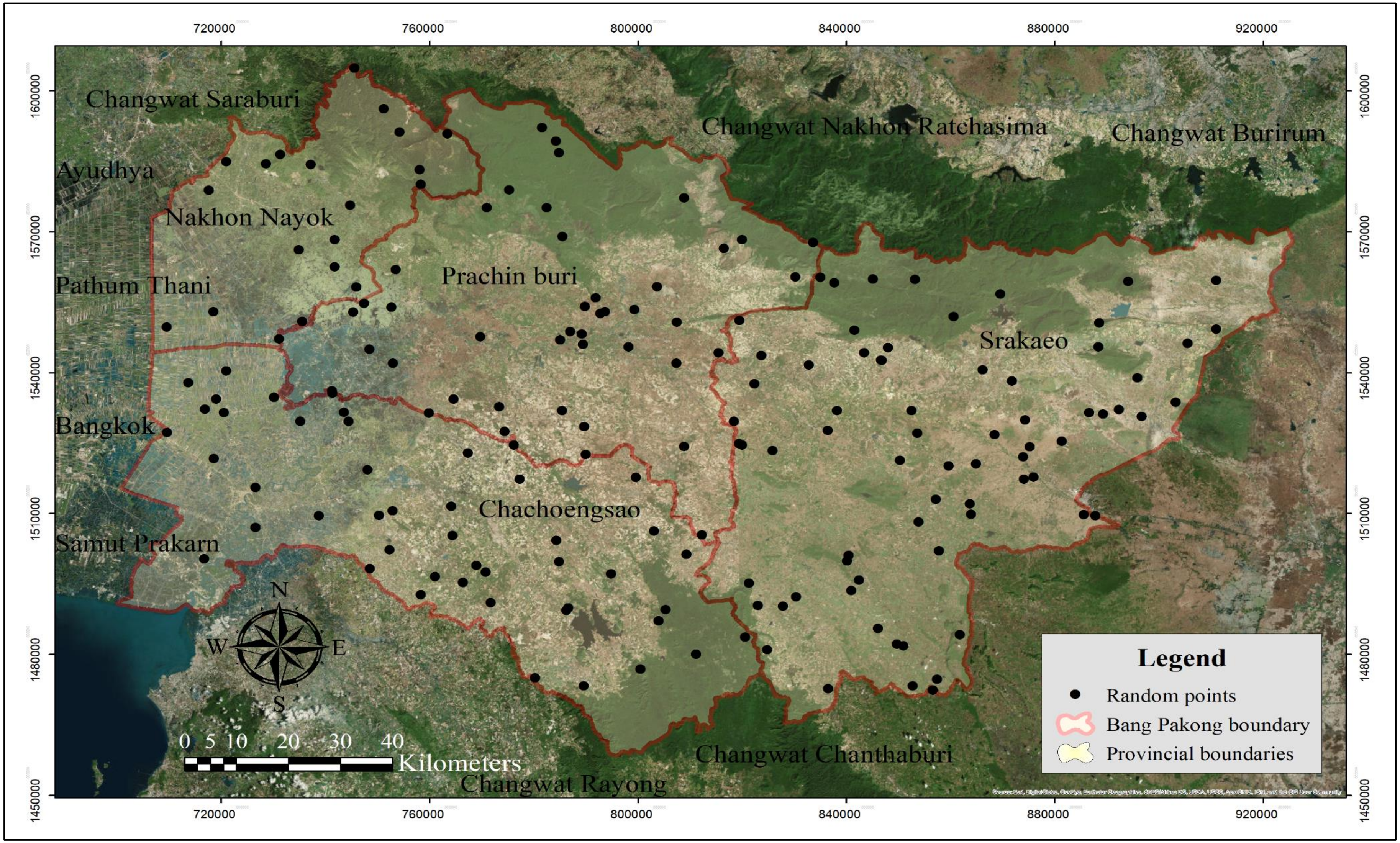


Figure 3.6 Random point positions for land use classification accuracy assessment derived from Google Earth Engine (2016).

Figure 3.4 shows ground check point position for aquaculture and industrial land with 76 planned points for the whole basin. The planned points are selected along the main road for the better access of land use checking. The planned points will be based on land use classification in 2016 from Land Development Department. To assess accuracy of such land use in the latest year, ground verification is needed. Based on the objective of this study, aquaculture land is one of the most changed land use in the study area and industrial land is also expanded increasingly in the basin which will be impacted on water resources in the future. Thus, I selected these sample land use types in order to check with the ground truth.

While other land use types are also necessary to check, I applied Arcgis in order to create 200 random points around the basin because the study area where it covers 4 provinces (Nakhon Nayok, Chachoengsao, Srakaeo and Prachin buri) is too large to ground check for every types of land use. The random points as shown in Figure 3.5 are created to scatter around the basin and the satellite image in 2017 from Google Earth Engine is the reference point.

To validate the accuracy of image classification result, field checks were conducted during October 2017 and November 2017. Due to the time lapse between the satellite images and the field check, which was conducted in 2017 while the current image classification from Land Development Department (LDD) is in 2016. Thus, the overall accuracy of land use classification might have some errors. However, the field data were mainly collected to provide a secondary source of information and to recheck any confusion identified of image classification.

There is also the previous study that assess accuracy of LDD, Junkaew, et al. (2015) using land use classification of LDD in the year 2015 for assessing suitable area for cassava crops in Kampheangphet province, Thailand. The study found that the overall accuracy of land use classification of LDD is 80.33% with the Kappa Coefficient 0.764.

Methodology Objective 2: To assess water pumping by different water users in Bang Pakong river basin during the dry season.

Table 3.12 : Analytical framework of the research objective 2

Objective 2	Research questions	Data collection	Outputs
- To assess water pumping by different water users in Bang Pakong river basin during the dry season	1. How much water they pump during the dry season? 2. How much water crop requirement in the dry season?	**Primary data** - In-depth interview with the relevant public organizations who works of water use. **Secondary Data** - Previous assessments of water uses from Department of Water Resources (DWR) - Evapotranspiration data of plants (Kc and Eto) for calculating the water consumption for agriculture. - The actual water need of rice farming. - The data of water requirement/ water demand of each water sector from Regional Irrigation Office 9th. - Shapefile of dry season rice in the basin level (4 provinces) in 2014-2017 from GISTDA.	1. The current data demonstrates water pumping/ water demand of each type of water sector in the basin. 2. Water requirement for agriculture crops (rice and Fish and shrimp farming) in the past 7 years (2009, 2013, 2016)

Methodology objective3: To investigate the data collection method and the information by public institutions in terms of land use and water use in Bang Pakong river basin.

Table 3.13 : Analytical framework of the research objective 3

Objective 3	**Research questions**	**Data collection**	**Outputs**
- To investigate the data collection method and the information by public institutions in terms of land use and water use in Bang Pakong river basin.	1. What are the public organizations that in charge of land use and water use in the Bang Pakong river basin ? 2. What are the issues of data in terms of land use and water use in Bang Pakong river basin ?	**Primary data** - In-depth interview with relevant public organizations who works in land use and water use analysis in the basin level.	- Identifying the main duties of each public organizations. - Identifying the issues in terms of data limitations that happened in the process of those public organization in the basin.

Methodology Objective 4: To project business as usual scenario trends in land use and water use in the Bang Pakong river basin by 2028

Table 3.14 : Analytical framework of the research objective 4

Objective 4	**Research questions**	**Data collection**	**Outputs**
- To project business as usual scenario trends in land use and water use in the Bang Pakong river basin by 2028.	1. What is the evolution of land use and water use in Bang Pakong river basin by 2028?	- Land use and Water use analysis from objective 1 and objective 2.	- The evolution of land use, water consumption by 2028

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Accuracy Assessment

An accuracy assessment of the classified images was performed by assessing sample points to check with ground-truthing. Overall accuracy of 83.26% (kappa coefficient 0.73) was obtained from the year 2016 (Table 4.1).

Table 4.1: Accuracy assessment of image classification

Ground reference	Classification by LDD					
	Agriculture land	Forest land	Miscellaneous land	Urban land	Water body	Total
Agriculture land	125		3	19	1	148
Forest land	1	35				36
Miscellaneous land		1	4	3		8
Urban land	7		2	53		62
Water body	1		2	3	3	9
Total	134	36	11	78	4	263

Overall Classification Accuracy: **84 %**

Producer's Accuracy (commission Error)

Agriculture land =	93.28%
Forest land =	97.22%
Miscellaneous land=	36.36%
Urban land=	67.95%
Water body =	75.00%

Overall Kappa Statistics: **0.74**

User's Accuracy (commission Error)

Agriculture land=	83.89%
Forest land=	97.22%
Miscellaneous land=	50.00%
Urban land =	85.48%
Water body=	33.33%

To calculate overall accuracy or the percentage of random points that are the same in both classified images and ground-truth. In this matrix, there are 220 points (125 agriculture, 35 forest, 4 miscellaneous, 53 urban and 3 water). It has a total of 263 random points.

For Kappa statistic in this error matrix is 0.74 (The kappa should be ranged from -1 to +1). Therefore in this case, the Kappa value 0.74 is good based on Tremblay (2005) degree of agreement.

From the Table 4.1 above, an accuracy assessment of image classification is compared to the Table 4.2 which there is a removal of some points that are not due to an error of image classification but instead, it is due to land use changes in the area from 2016 to 2017. In the Table 4.2, I removed some points which can be clearly identified from 3 types of land use; agriculture land, miscellaneous land and urban land.

Table 4.2: Accuracy assessment of image classification after removal of explained differences

Ground reference	Classification by LDD					
	Agriculture land	Forest land	Miscellaneous land	Urban land	Water body	Total
Agriculture land	125			5	1	131
Forest land	1	35				36
Miscellaneous land		1	4	3		8
Urban land				53		53
Water body	1			3	3	7
Total	127	36	4	64	4	235

Overall Classification Accuracy: **94 %**

Producer's Accuracy (commission Error)

Agriculture land =	98.43%
Forest land =	97.22%
Miscellaneous land=	100.00%
Urban land=	82.81%
Water body =	75.00%

Overall Kappa Statistics: **0.90**

User's Accuracy (commission Error)

Agriculture land=	95.42%
Forest land=	97.22%
Miscellaneous land=	50.00%
Urban land =	100.00%
Water body=	42.86%

Based on ground truth verification in the study area and Google Earth Engine in 2017, I compared each point that has been changed. However, some points from the Table 4.1 are not the errors of image classification by LDD but the points are changed because of land use changes. For example, urban land which the error values occurred significantly. The total points of urban land in the Table 4.1 is 78. It can be clearly seen that urban land changed to agriculture land up to 19 points which seems to be abnormal for land use changes. Moreover, another 6 points of urban land are changed into miscellaneous land and water body but they are matched compared with ground truth verification. Therefore, the abnormality occurred with those 19 points (or approximately 24% of it).

After comparing all 19 points with ground truth verification and Google Earth Engine, there are 14 points of 19 points that can be identified it is not an error of classification but all 14 points are occurred due to land use changes. Those 14 points changed in the year 2017 into 8 points in aquaculture land (fish, shrimp and frog farming), 4 points to perennial crops (Eucalyptus tree) and 2 points to paddy field. The previous year in 2016, it was an urban land where used to be a road, village, institutional land and industrial land. It is found later that in 2017, most of aquaculture land have been changed from village to fish and shrimp pond because the farmers dig the pond for raising fish or shrimp or even frog to earn more money. Similarly to 4 points of perennial crop (Eucalyptus crops) and another 2 points of paddy field, have been expanded along the road due to a commercial purpose. As a consequence, in the Table 4.2, I removed 14 points out of 19 points for urban land that changed into agriculture in 2017. Thus, the total points of urban land is modified to 64 points.

In terms of miscellaneous land, it is also one of land use type that changed variously to other land use in 2017. In the Table 4.1, the total points of miscellaneous land is 11. After comparing to ground verification, I removed 7 points out of 11 points. For those another 4 points are remained because the points are matched with ground verification. From 7 points that are removed, 3 points of it have been changed into agriculture land (Paddy field and fish pond), another 2 points of it have been changed into urban land (Mills and factory) and the last 2 points of it have been changed into water body (water area and lotus pond). It is not surprisingly that why miscellaneous land changed to various type of other land uses because it is a deserted land, once the land is not occupied, it can be applied to use to various purposes. As a consequence, in the Table 4.2, I finally removed 7 points out of 11 points of miscellaneous land in 2017. Thus, the total points of miscellaneous land is modified to only 4 points.

Finally, in the case of agriculture land which is the most proportion of all land use type in the study area. In the Table 4.1, the total points of agriculture land is 134. After comparing to ground verification, I removed 7 points which can clearly identified how it is changed from all 134 points. From 7 points that are removed, it can be identified that all of it has been changed into urban land, Especially in mills, factories and department store. As a consequence, in the Table 4.2, I removed 7 points out of 134 points of agriculture land in 2017. Thus, the total points of agriculture land is modified to 127 points.

Therefore, an accuracy assessment of the classified images after removing those points in the Table 4.2, overall accuracy is 94% and kappa coefficient is 0.90.

4.2 Land Use Change in Bang Pakong river basin

Land use change was detected from land use maps derived from satellite images of the year 2002, 2006, 2009, 2013 and 2016. Table 4.2 summarizes the area coverage of each land use type based on the satellite image interpretation. In 2002, agriculture land (paddy field, field crop, perennial, orchard, horticulture, pasture and farm house, aquatic plant and aquaculture land) is the crucial land use type in the study area as it covers more than 60% of the area, compared with forest land, miscellaneous land, urban land and water body, which covered around 24%, 3%, 5% and 1%, respectively. As shown in Table 4.3, agriculture land and forest land were also the major land uses in 14 years period while miscellaneous land surprisingly decreased in the year 2016. Interestingly, water body strongly increased up to 6% in 2016.

The bar graph in Figure 4.1 below illustrates the percentage of land use type in the study area in 5 land use types: Agriculture land, forest land, miscellaneous land, urban land and water body during 2002- 2016. The percentage of agriculture land is the most proportion of all land use types following with forest land, urban land, miscellaneous and water body, respectively.

Interestingly, water body is one of the most changed areas in the study area. In the year 2002, 2006, 2009, and 2013 the area slightly changed. However, the latest year in 2016, the percentage of change strongly increased up to 6%. As compare Figure 4.2, 4.3, 4.4 and 4.5 which show the map of land use type in the study area in 2002, 2006, 2009 and 2013 with Figure 4.6, the map of land use type in 2016, the map shows 3 majors changed of water body in the whole Bang Pakong river basin.

The 3 majors changed of water area are in Hanuman sub-basin, Klong Phra Sathung sub-basin and Klong Phra Prong sub-basin in Prachinburi province. The most expanded water area is in Hanuman sub-basin. It expanded approximately from 516 ha in the year 2013 to 2,065 ha in 2016. According to the data on water resources from Department of Water Resources (DWR) report (2008), water resources development projects have been developed in the basin in order to increase a capacity of water storage which had only 20 projects in the past (include both large-scale and medium-scale projects). However, the basin itself had only 2 large-scale projects which are Klong Siyat reservoir and Khundan Prakanchol reservoir.

The overall volume capacity for all projects is only 813 mcm which seems not to be enough water for several sectors in the basin. Therefore, water resources development projects have been planned to develop in the future for 19 projects and it would help increasing water storage for 1,362 mcm. As a result, in 2016, several water resources development projects have been developed in the basin including of a large-scale project in Hanuman sub-basin or Huay Sa-Mong reservoir as shown in Figure 4.6, Klong Phra sathung reservoir in Klong Phra Sathung sub-basin where it covers 1,162 ha.

Moreover, the land use map in 2002-2016 show a clear expansion of urban and built-up land in 2002, 2006 and 2009. The densest built-up area expanded in the Central, Southwest and along the main road as seen in the map from 2002-2016. The formerly land use was occupied by agriculture land and turned into urban land after in the year 2002.

Decreasing of forest land in the year 2002 is another clearly land use changed**.** Some parts of forest land in 2002 particularly in Central and East sides of the basin have been turned into agriculture land and urban land in 2006.

By calculating the area in Table 4.4, the study found that the major changes are firstly miscellaneous area where it continually increased during 2002-2013 then it rapidly decreased by the year 2016. It is very clear that miscellaneous areas were turned into agriculture, urban and water land. Meanwhile water body within in this 14 years period has slightly increased every year but interestingly that in the last 2 years between 2013 and 2016, the area of water body significantly rose up almost 10 times due to a construction of dam at the upstream river.

Table 4.3 : Coverage area of the land use categories based on image interpretation.

Land use type	2002		2006		2009		2013		2016	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Agriculture	1,280,449	67	1,194,818	62	1,194,132	62	1,198,471	63	1,187,404	62
Forest	474,689	25	460,950	24	457,278	24	457,031	24	453,415	24
Miscellaneous	49,629	3	66,673	3	73,442	4	79,591	4	10,552	1
Urban	86,915	5	157,778	8	154,193	8	137,927	7	151,810	8
Water	21,057	1	33,217	2	34,390	2	40,417	2	110,254	6
No data	697	0								
Total	1,913,436	100	1,913,436	100	1,913,436	100	1,913,436	100	1,913,436	100

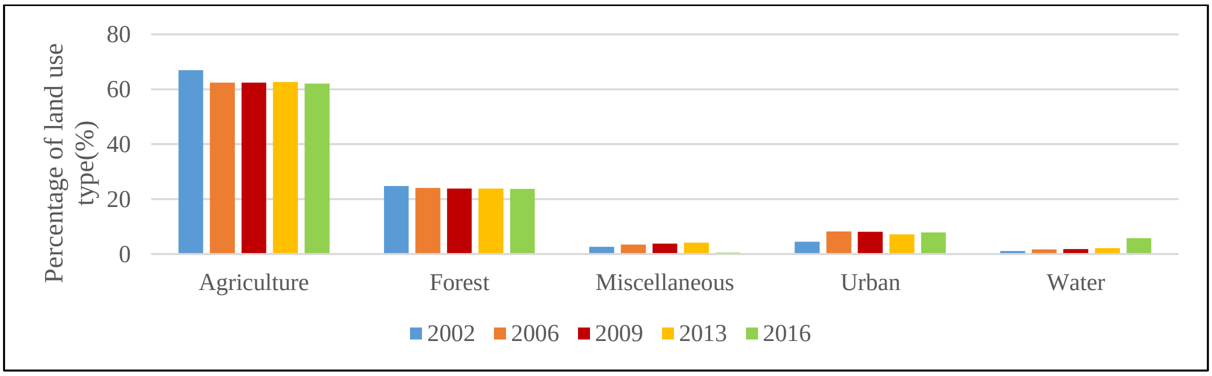


Figure 4.1 : Land use type in the study area (2002-2016)

Table 4.4 : Area of land use change in 2002 – 2016

	2002-2006				2006-2009			
Land use type	Area in 2002 (ha)	Area in 2006 (ha)	Changed area (ha)	Changed percentage (%)	Area in 2006 (ha)	Area in 2009 (ha)	Changed area (ha)	Changed percentage (%)
Agriculture	1,280,449	1,194,818	-85,631	-7	1,194,818	1,194,132	-686	0
Forest	474,689	460,950	-13,739	-3	460,950	457,278	-3,672	-1
Miscellaneous	49,629	66,673	17,043	34	66,673	73,442	6,770	10
Urban	86,915	157,778	70,863	82	157,778	154,193	-3,585	-2
Water	21,057	33,218	12,160	58	33,217	34,390	1,173	4

	2009-2013				2013-2016			
Land use type	Area in 2009 (ha)	Area in 2013 (ha)	Changed area (ha)	Changed percentage (%)	Area in 2013 (ha)	Area in 2016 (ha)	Changed area (ha)	Changed percentage (%)
Agriculture	1,194,132	1,198,471	4,338	0	1,198,471	1,187,404	-11,067	-1
Forest	457,278	457,031	-248	0	457,031	453,415	-3,616	-1
Miscellaneous	73,442	79,591	6,148	8	79,591	10,552	-69,039	-87
Urban	154,193	137,927	-16,266	-1	137,927	151,810	13,884	10
Water	34,390	40,417	6,027	18	40,417	110,254	69,837	173

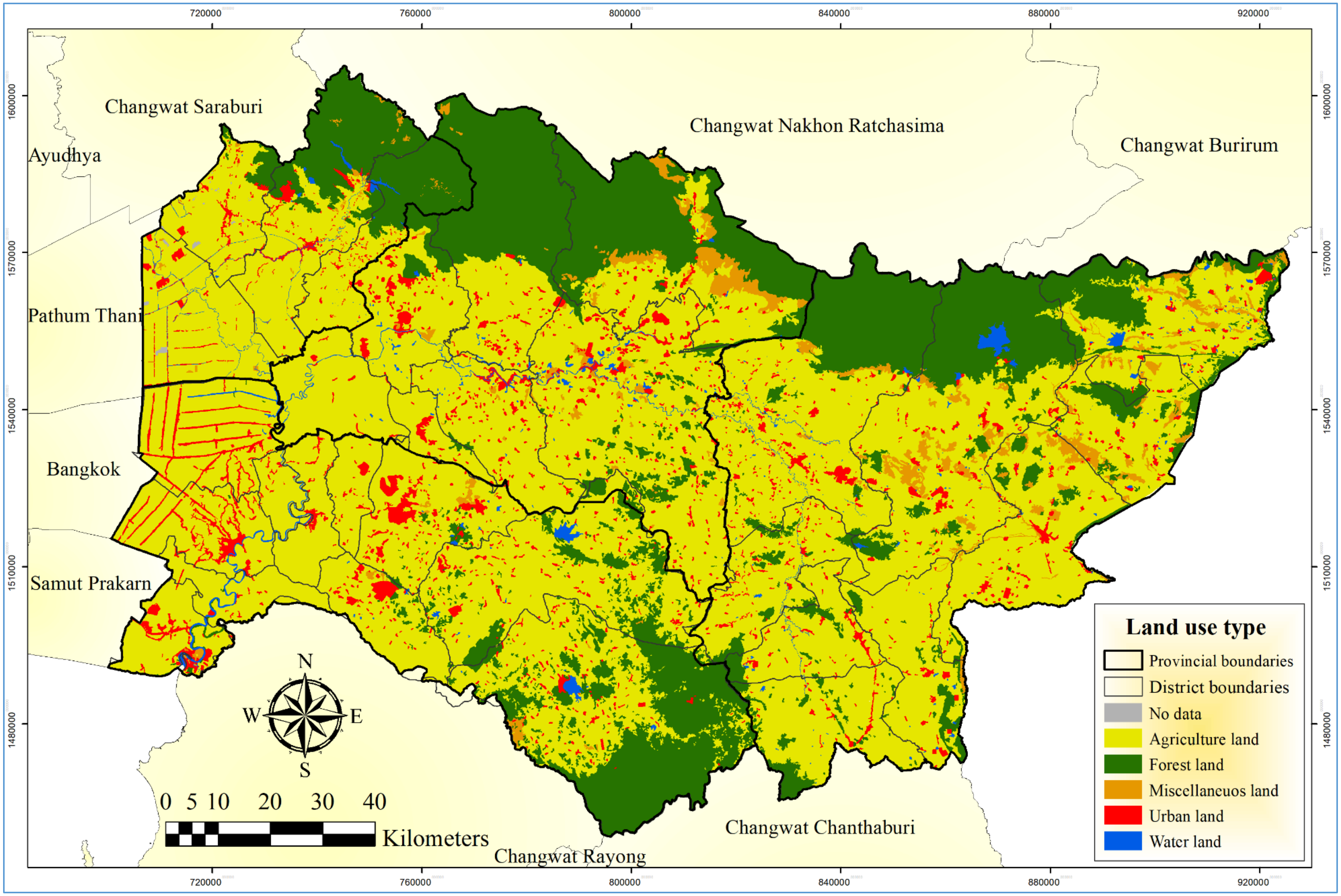


Figure 4.2 Land use type in the study area in 2002

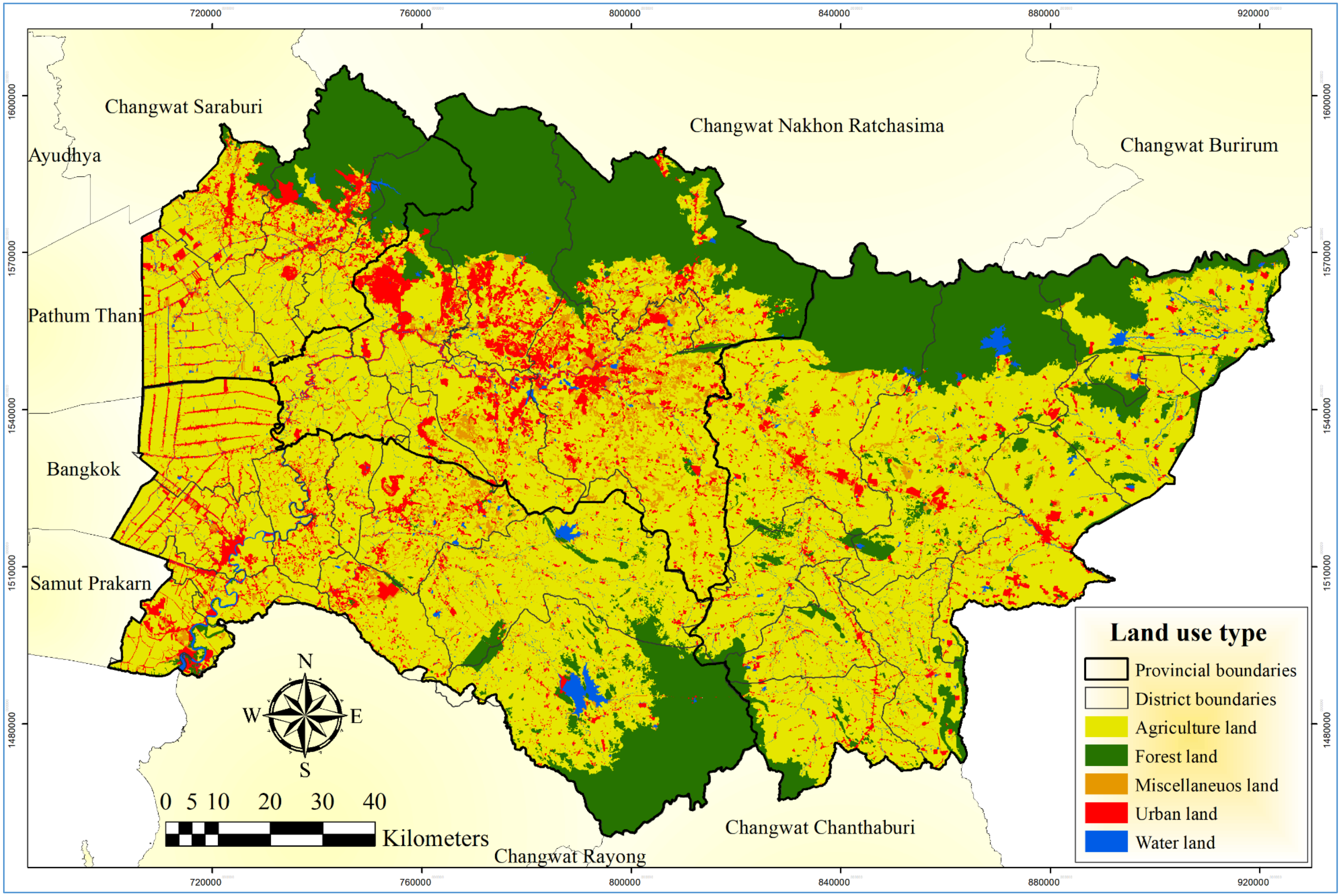


Figure 4.3 Land use type in the study area in 2006

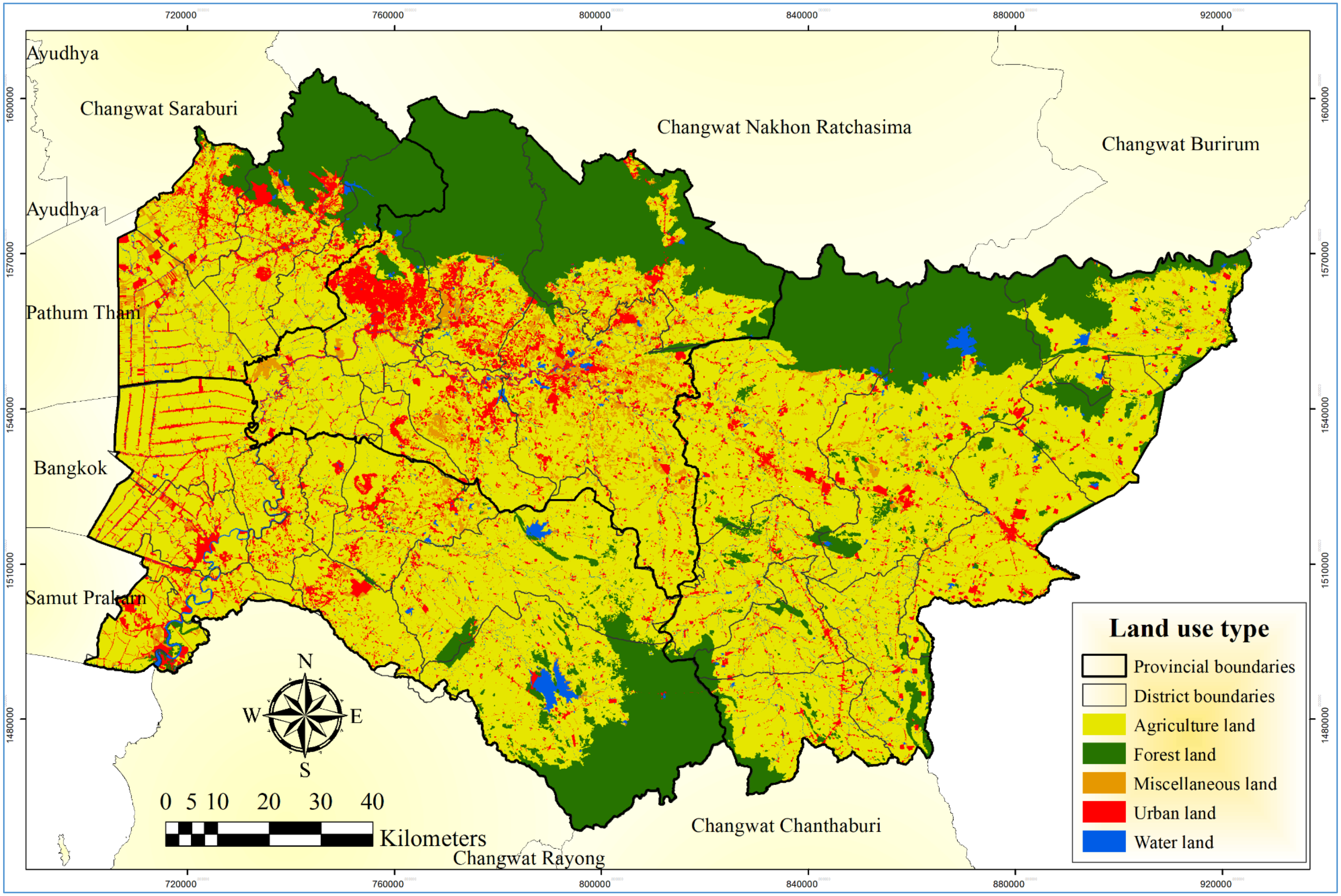


Figure 4.4 Land use type in the study area in 2009

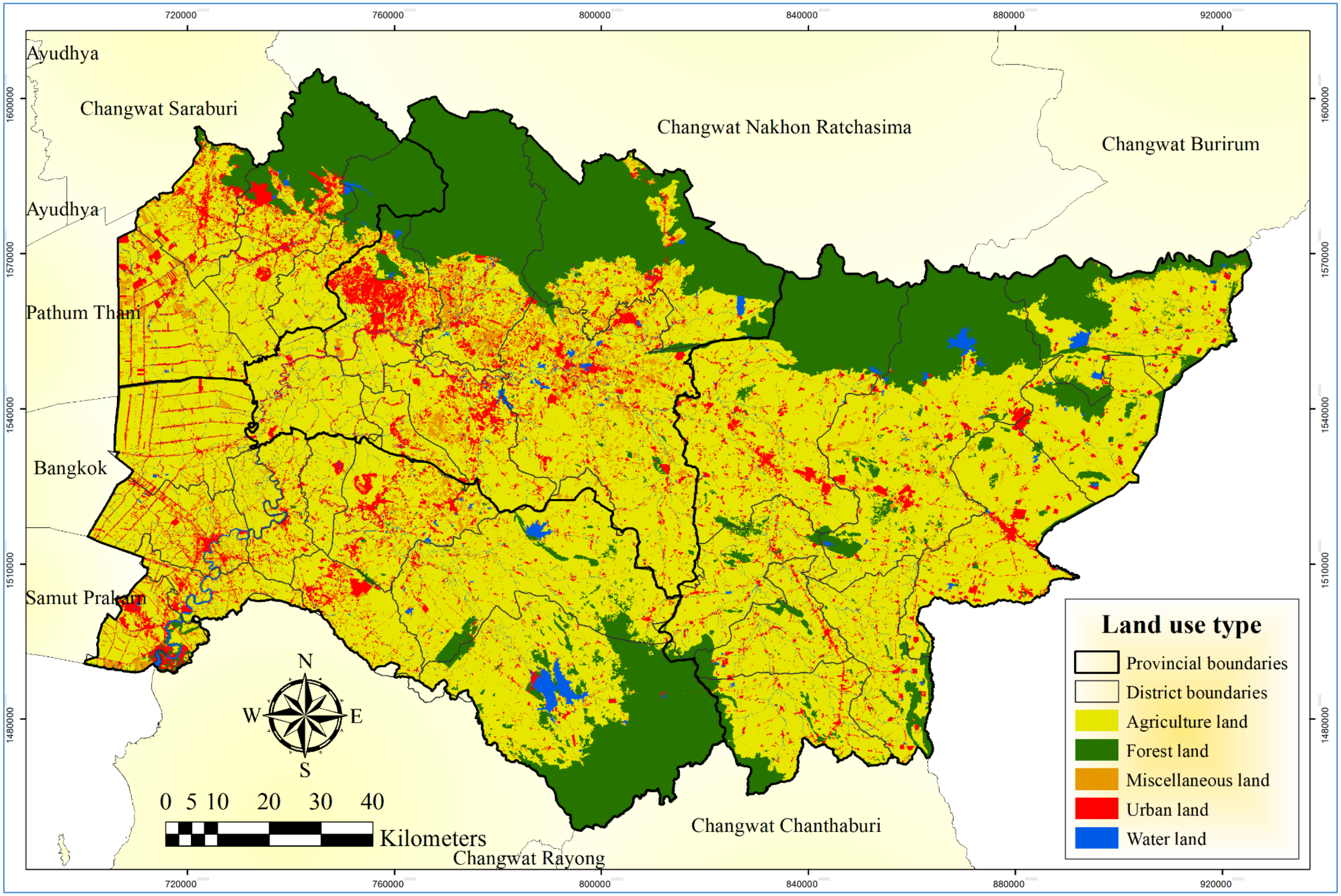


Figure 4.5 Land use type in the study area in 2013

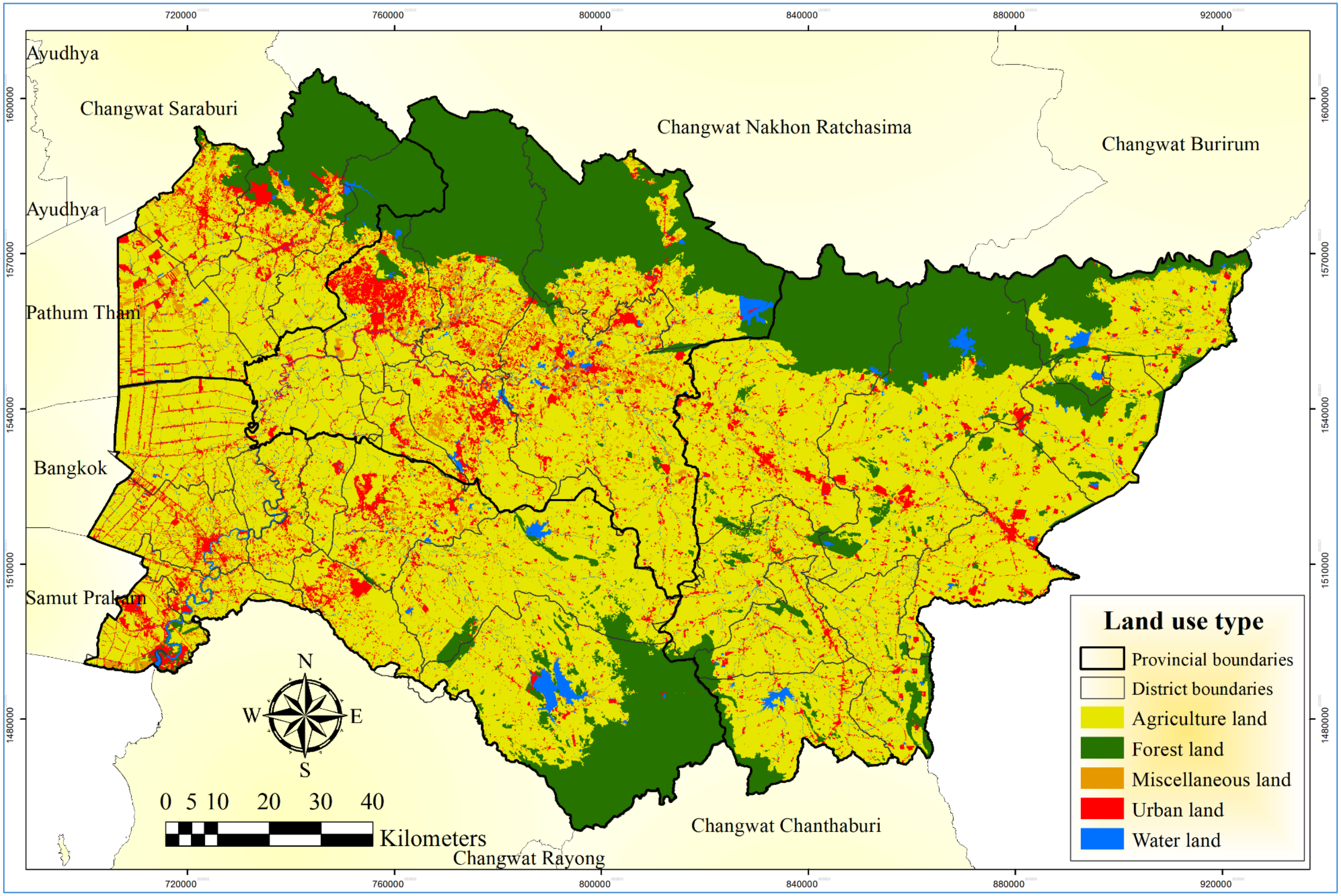


Figure 4.6 Land use type in the study area in 2016

4.2.1 Land use change on each land use category

Table 4.5 : Land use/cover change matrix showing percentage of land encroachment in Bang Pakong river basin.

Landuse/cover categories	Year 2016					
Year 2006	Agriculture land	Forest land	Miscellaneous	Urban land	Water body	Class total
Agriculture land	92.19	0.61	0.70	3.47	3.03	100
Forest land	2.73	96.18	0.05	0.32	0.73	100
Miscellaneous	42.81	2.49	0.51	6.14	48.04	100
Urban land	24.72	0.33	1.01	65.17	8.77	100
Water body	17.31	1.80	0.16	6.13	74.60	100

For the land use changes or land encroachment for all land use categories during the last 10 years, Table 4.5**,** a change detection matrix shows that forest land and agriculture land are the most used land type in the study area, more than 90% of all land use types.

Although Forest land is covered more than 90% of all the area, but it does not change much into other land because of it is a conservative forest in the National Park. Thus, no allowance of land encroachment in the forest area while agriculture land, the second used of land around 90% also does not change much into another land use type except for changing into urban area as it is well know that a conversion of agriculture into urban is common as urbanization can take place throughout the time due to the population increase. Interestingly that another obvious conversion of agriculture in this table is water body, around 3% of agriculture converted into water body. It is because in the year 2016, there are new reservoirs in the basin were built, especially Huay Samong Dam in the upper part of the basin,that is why there is conversion of agriculture into water body in 2016.

Urban land in the study area has been converted a lot into agriculture land due to the farmers invest more for fish and shrimp farming, they dig the pond in their own land or rent the land for it. Moreover, some farmers cultivate Eucalyptus tree along the road.

As it is mentioned above about the new reservoirs in the upper part of the basin in 2016, this reason is the major factor that increase the percentage or water body in the year

4.2.2 Agriculture land

Agriculture land in the study area has slightly decreased during in this 14 years period. It occupied averagely 1,211,055 hectare or 63% of all land use types which is the most proportion of land use. Agriculture land occupied 1,280,449 hectare or 67% in 2002 and decreased by 62%, 62%, 63% and 62% in 2006, 2009, 2013 and 2016, respectively.

Agriculture land based on Land Development Department (LDD) image interpretation, is classified into 9 types which are integrated farm, paddy field, field crop, perennial crop, orchard, horticulture, pasture and farm house, aquatic plant and aquaculture land.

However, if categorizing all agricultural activities, it can be categorized into Paddy field, field crop, perennial crop, orchard and aquaculture land. The graph in Figure 4.7 shows a trend of change in each type of agriculture land from 2002 to 2016. It illustrates that Paddy field, Field crop and Orchard tend to decrease while perennial crops and aquaculture land tend to increase in the future. There are 5 major types of agriculture land which are paddy field, field crop, perennial, orchard and aquaculture land as shown the percentage in Table 4.5. The percentage of agriculture type shows that paddy field is the most proportion of agriculture type in 2002-2016, following with field crop, perennial crops, orchard and aquaculture land (Figure 4.7).

The graph shows the proportion of main types of agriculture land in the study area compared during in the year 2002, 2006, 2009 and 2016. While paddy field, field crop and orchard tend to decrease, perennial crops and aquaculture land tend to increase in the future.

From the Figure 4.8- 4.12 below, the maps show a clear scattering of each main type of agriculture land in the basin. Perennial crops are expanded from 2002 until 2016 mostly in the middle of the basin in Prachinburi and Chachoengsao provinces while aquaculture land is expanded in Paddy field area in the West side of the basin, covers some parts of Nakhon Nayok and Prachinburi provinces and mostly part where it located along with Bang Pakong river in Chachoengsao province due to a suitable geography as the Bang Pakong river discharges into the Gulf of Thailand.

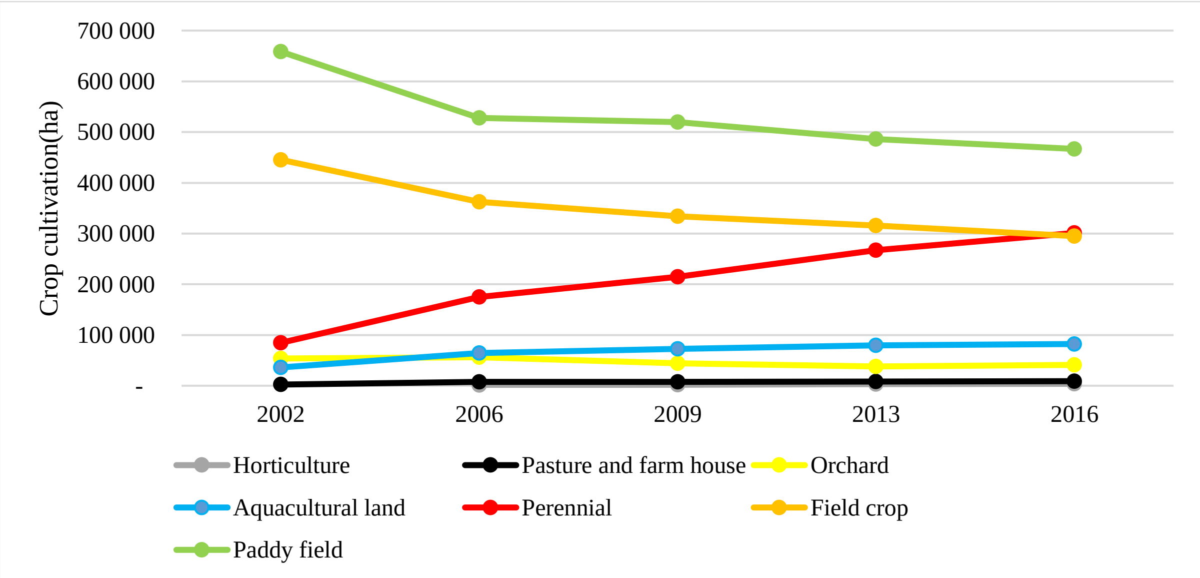


Figure 4.7: Main types of agriculture land in the study area.

Table 4.6: Coverage area of each type of agriculture land.

Type of agriculture land	2002 (ha)	%	2006 (ha)	%	2009 (ha)	%	2013 (ha)	%	2016 (ha)	%
Integrated farm/Diversified farm	-	-	40	0	33	0	16	0	20	0
Paddy field	658,522	51	527,958	44	519,436	43	486,409	41	466,791	39
Field crop	445,404	35	362,529	30	333,878	28	315,785	26	294,966	25
Perennial	84,587	7	174,663	15	214,634	18	266,963	22	301,090	25
Orchard	53,505	4	56,174	5	44,264	4	38,032	3	41,210	3
Horticulture	-	-	1,450	0	1,648	0	2,974	0	3,821	0
Pasture and farm house	2,356	0	7,591	1	7,845	1	8,450	1	9,015	1
Aquatic plant	-	-	50	0	118	0	98	0	91	0
Aquaculture land	36,075	3	64,362	5	72,811	6	79,744	7	82,241	7
Total	1,280,449	100	1,194,818		1,194,667		1,198,471		1,199,245	

A Description of agriculture types shows an example of each agriculture types in Prachinburi province between 2016-2017 to see the types of plants cultivated in the province.

Table 4.7 : Description of agriculture types in Prachinburi province in 2016-2017
Source: Prachinburi Agricultural Extension office, 2017

Type of agriculture land	Type of plants	Cultivated area (rai)
Paddy field	In-season rice	398,023
	Off-season rice	138,269
Field crop	Casava	128,747
	Maize	17,654
	Sweet corn	23
	Sugarcane	47,322
	Long bean	17
	Cucumber	7
	Watermelon	3,720
	Papyrus	241
	Acacia	800
Perennial crop	Para rubber	28,712
	Oil Palm	16,155
	Bamboo	22,919
Orchard	Santol	4,037
	Lady Finger banana	158
	Pisang Awak banana	1,541
	Jack fruit	1,685
	Rambutan	359
	Rose apple	29
	Durian	2,154
	Lime	2,937
	Mango	8,044
	Papaya	715
	Marian plum	1,568
	Coconut	1,223
	Lantern Tree	919
	Mangosteen	1,473
	Longan	738
	Langsat	394
	Pomelo	6,534
	Lychee	42
Total		837,159

There are 5 major types of agriculture land which are paddy field, field crop, perennial, orchard and aquaculture land as shown the percentage in Table 4.5. The percentage of agriculture type shows that paddy field is the most proportion of agriculture type in 2002-2016, following with field crop, perennial crops, orchard and aquaculture land (Figure 4.7).

The graph shows the proportion of main types of agriculture land in the study area compared during in the year 2002, 2006, 2009 and 2016. While paddy field, field crop and orchard tend to decrease, perennial crops and aquaculture land tend to increase in the future.

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As this study is based on dry season basis, generally, the source of water those agricultural crop depends on is different. Paddy field, field crop and orchard depend the water source on rainfall while perennial crops and aquaculture depend on the irrigated water. Thus, perennial crops and aquaculture land are conducted to analyze its dynamic of change including of its driver of change in the study area.

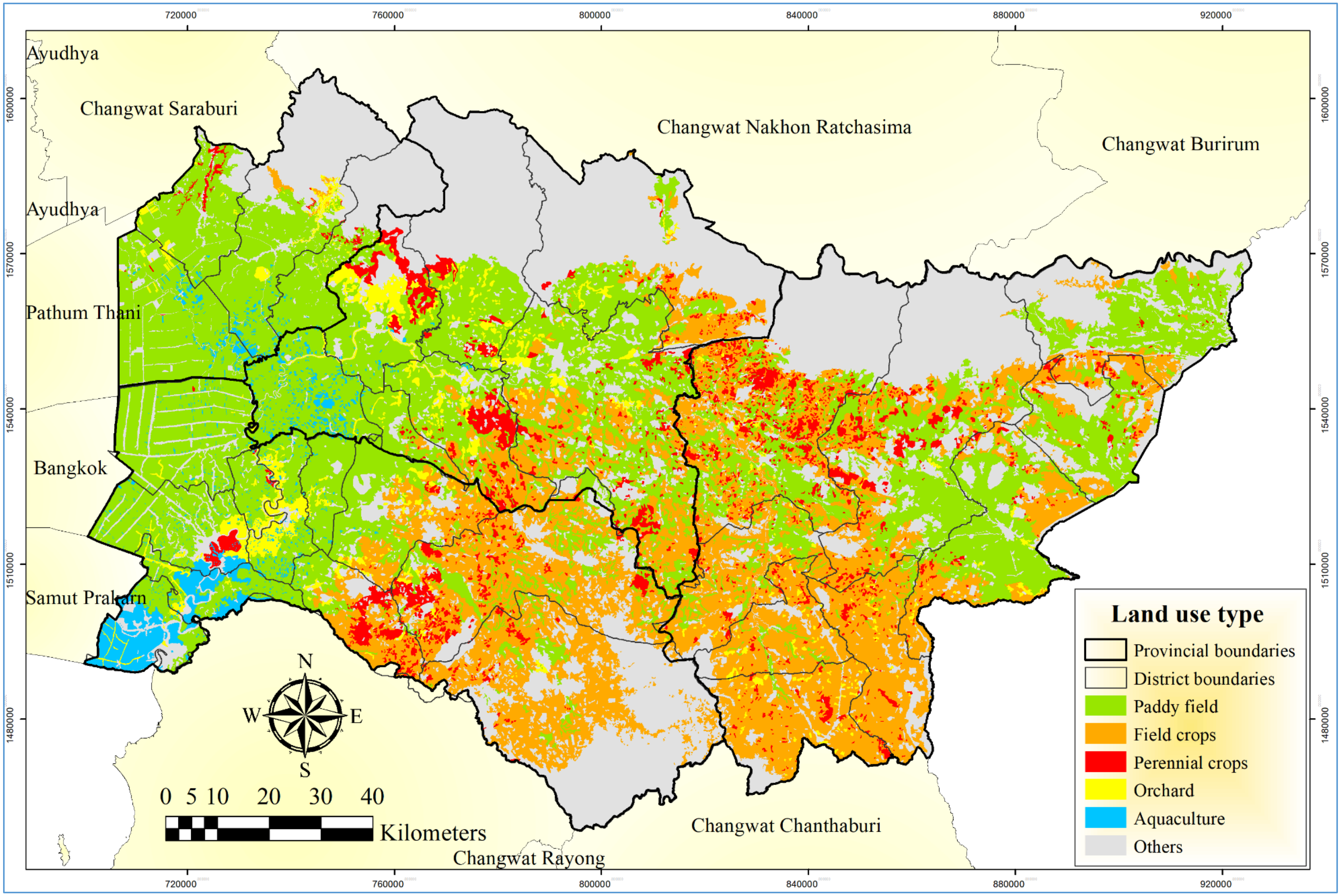

Figure 4.8: Main types of agriculture land in the study area in 2002.

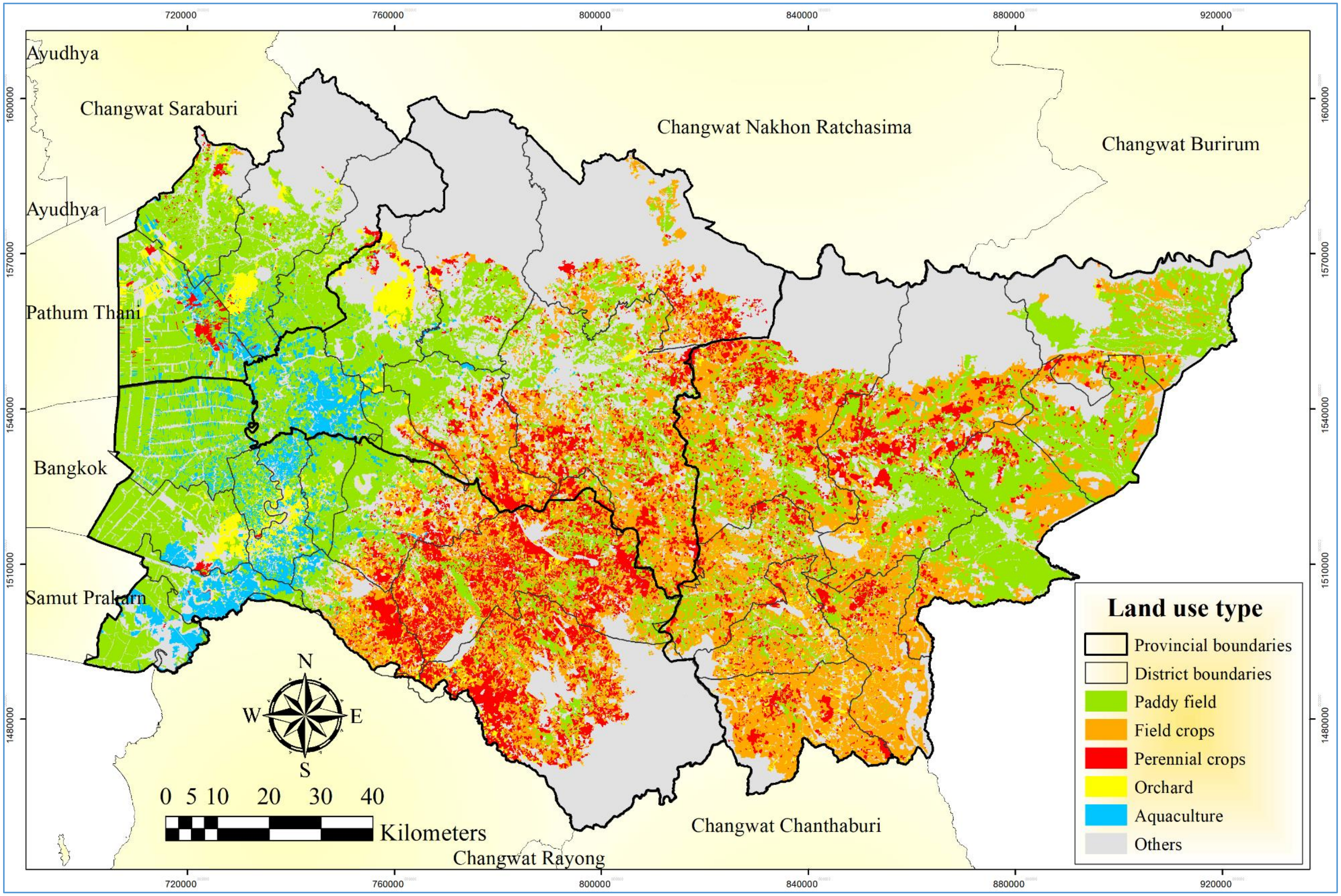

Figure 4.9 : Main types of agriculture land in the study area in 2006.

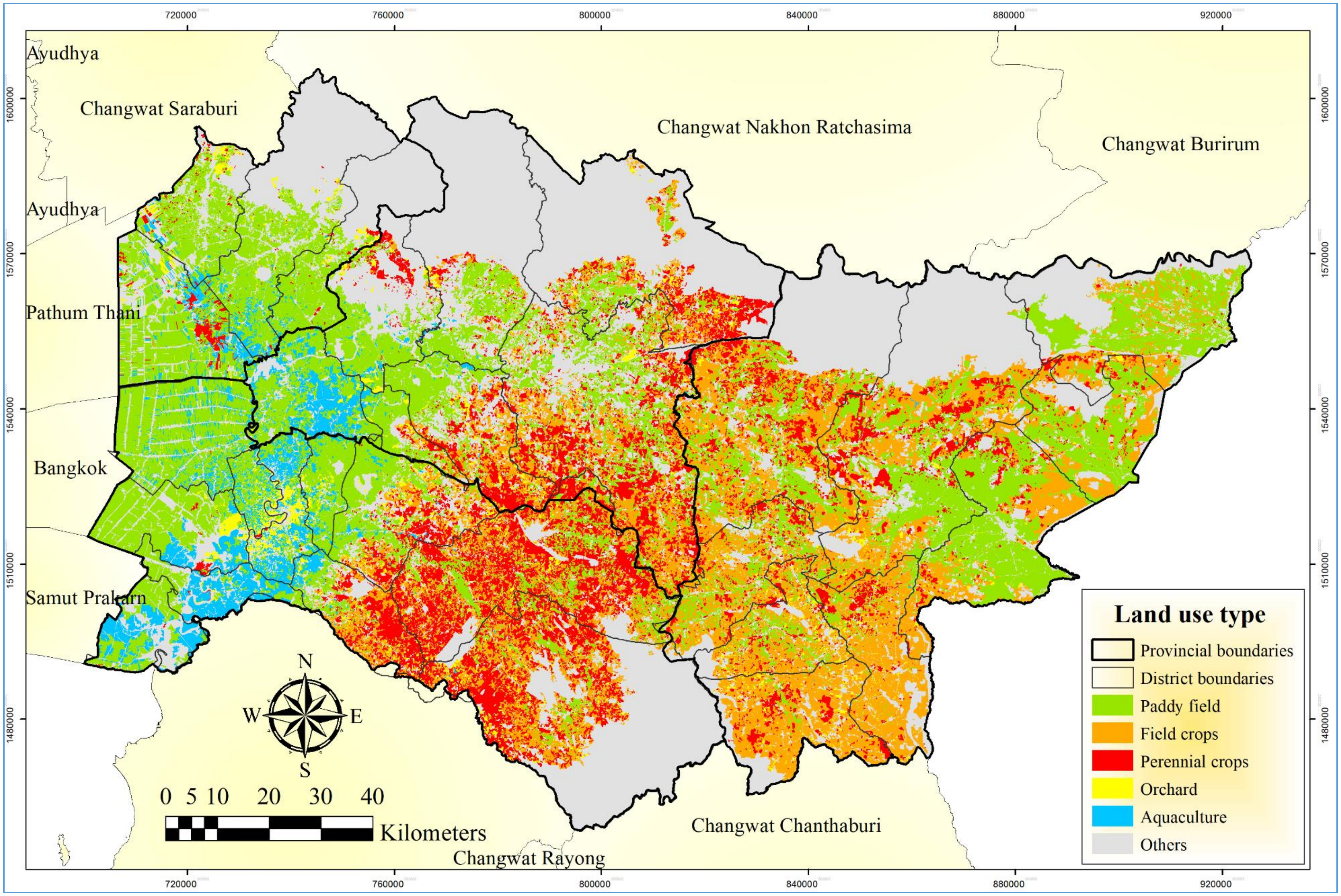

Figure 4.10: Main types of agriculture land in the study area in 2009.

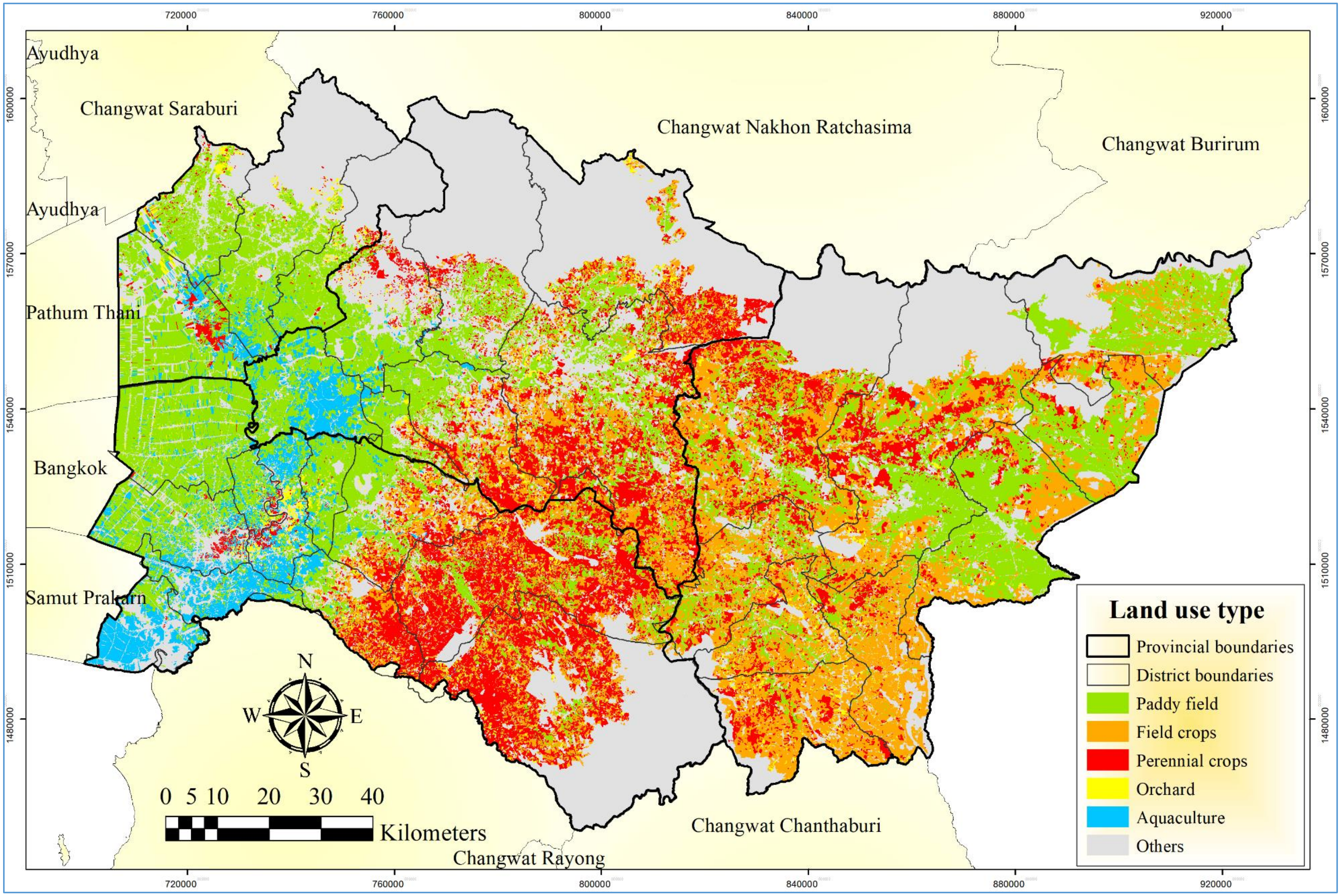

Figure 4.11: Main types of agriculture land in the study area in 2013.

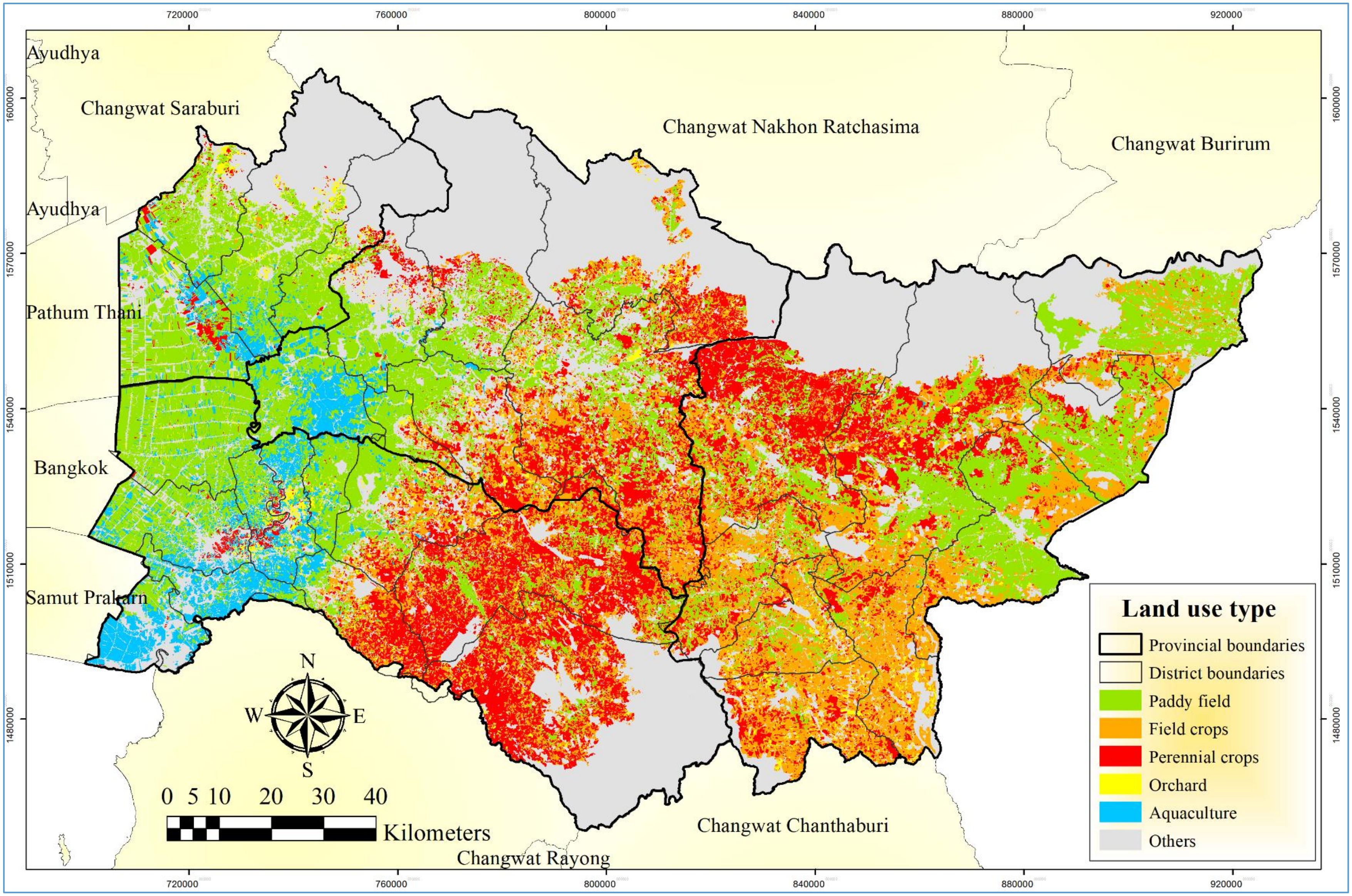

Figure 4.12 : Main types of agriculture land in the study area in 2016

- **Perennial crops**

As shown in the Figure 4.7**,** the graph demonstrates an increasing of perennial crops and aquaculture land in the study area while other agriculture land use tend to decrease.

Regarding to Figure4.13- 4.17 below, the maps show an expansion of only perennial crops from the year 2002-2016 for the whole Bang Pakong river basin. It can be seen from the maps that there is an increasing of perennial crops, especially in the middle and eastern sides of the basin or mostly in Prachinburi, Chachoengsao and Sa Kaew provinces.

From the map in 2002 (Figure4.13), perennial crops were cultivated in some parts of Nakhon Nayok province but mainly parts in Prachinburi, Chachoengsao and Sa Kaew provinces. Then in the year 2006, a concentration of perennial crops was found in Chachoengsao province than other provinces. As shown in Table 4.6, the area of perennial crops in Chachoengsao province from LDD in the year 2016 is over 130,000 ha or 41% for the whole basin while the crops in Sa Kaew is 35%, prachinburi is 22% and Nakhon Nayok is only 2%.

However, not only the perennial crops are increasing year by year since 2002 until 2016, but in each province itself, the area of crops are also increasing and tend to increase in the future as shown in the Table 4.6. From the maps below, it can be seen that the expansion of perennial crops will be cultivated densely at the province borders because the nearby areas have a similar geography and suitability of lands.

The following figures show that perennial crops first expanded in Chochoengsao province, and for the past years it has been expanded in the upstream part of the basin in Prachinburi province.
In Chachoengsao province, Sanam Chaikhet and Tha Takiap districts are the most cultivated perennial crops compared with other districts in Chachoengsao province while Kabinburi, Nadi and Srimahapho districts are the most cultivated of perennial crops in Prachinburi province. For Sa Kaew provinces, Muang Srakaeo and Wattana Nakhon districts are the most cultivated areas.

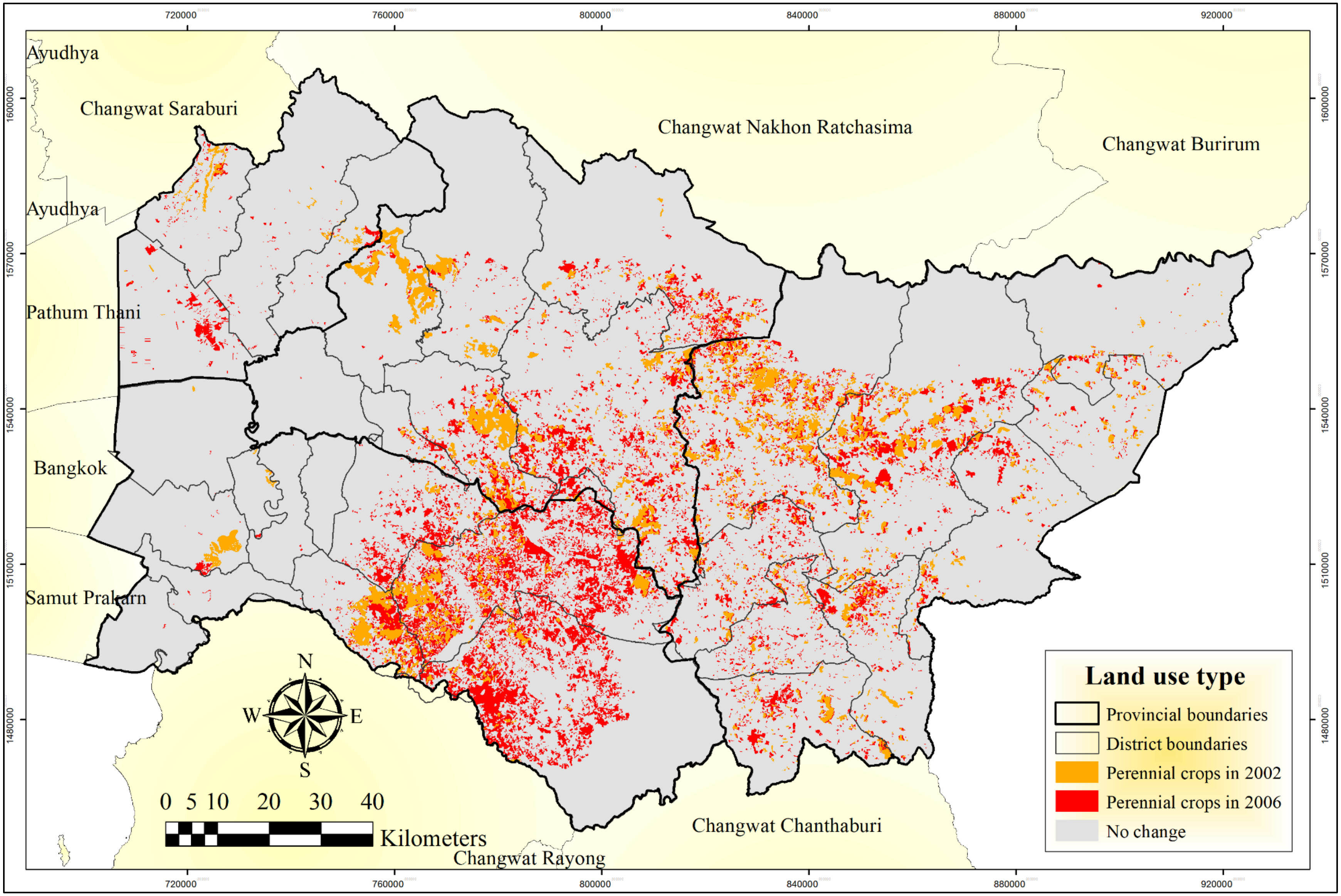

Figure 4.13 : Expansion of perennial crops in the study area compared between 2002 and 2006

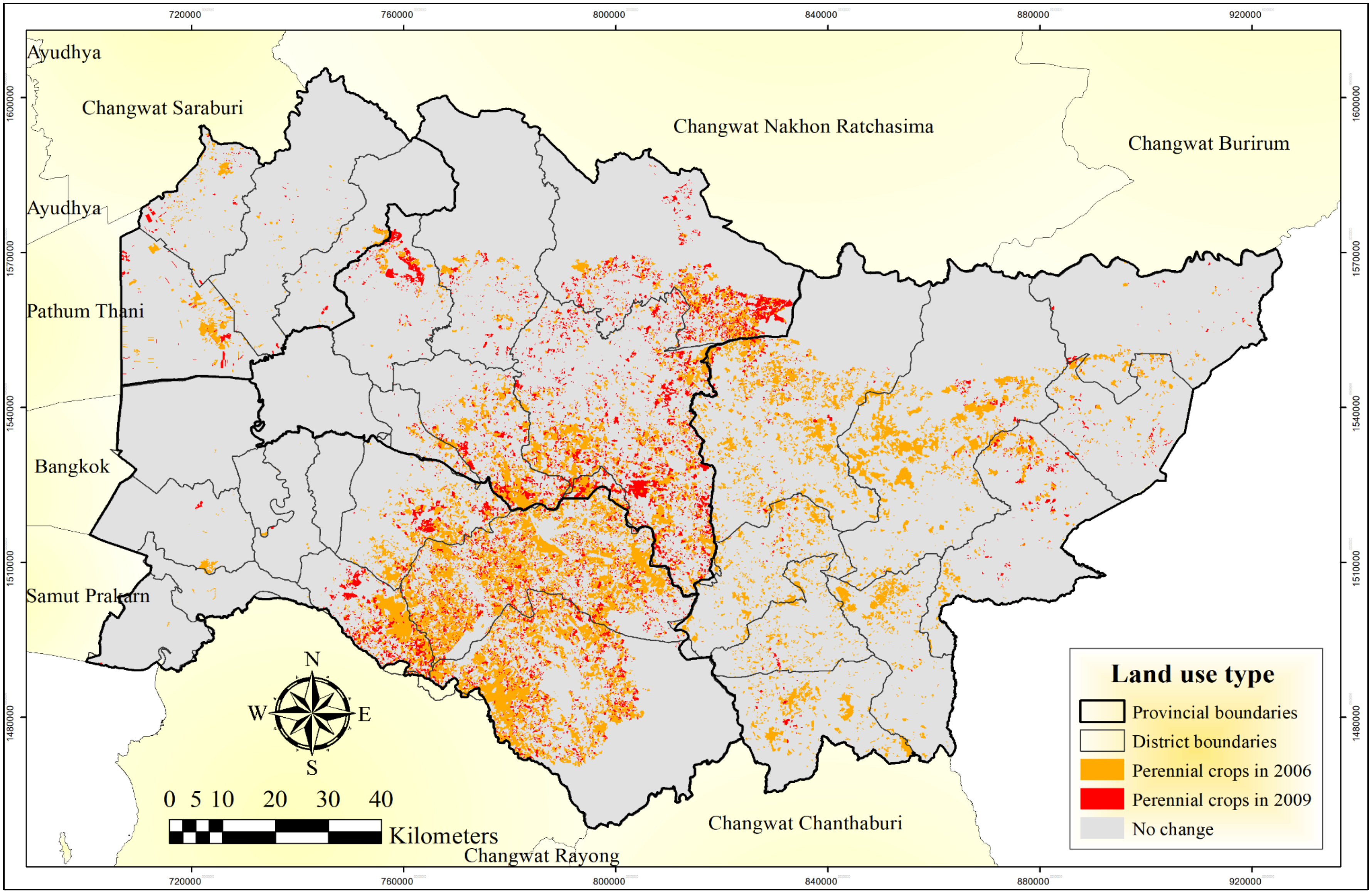

Figure 4.14 : Expansion of perennial crops in the study area compared between 2006 and 2009

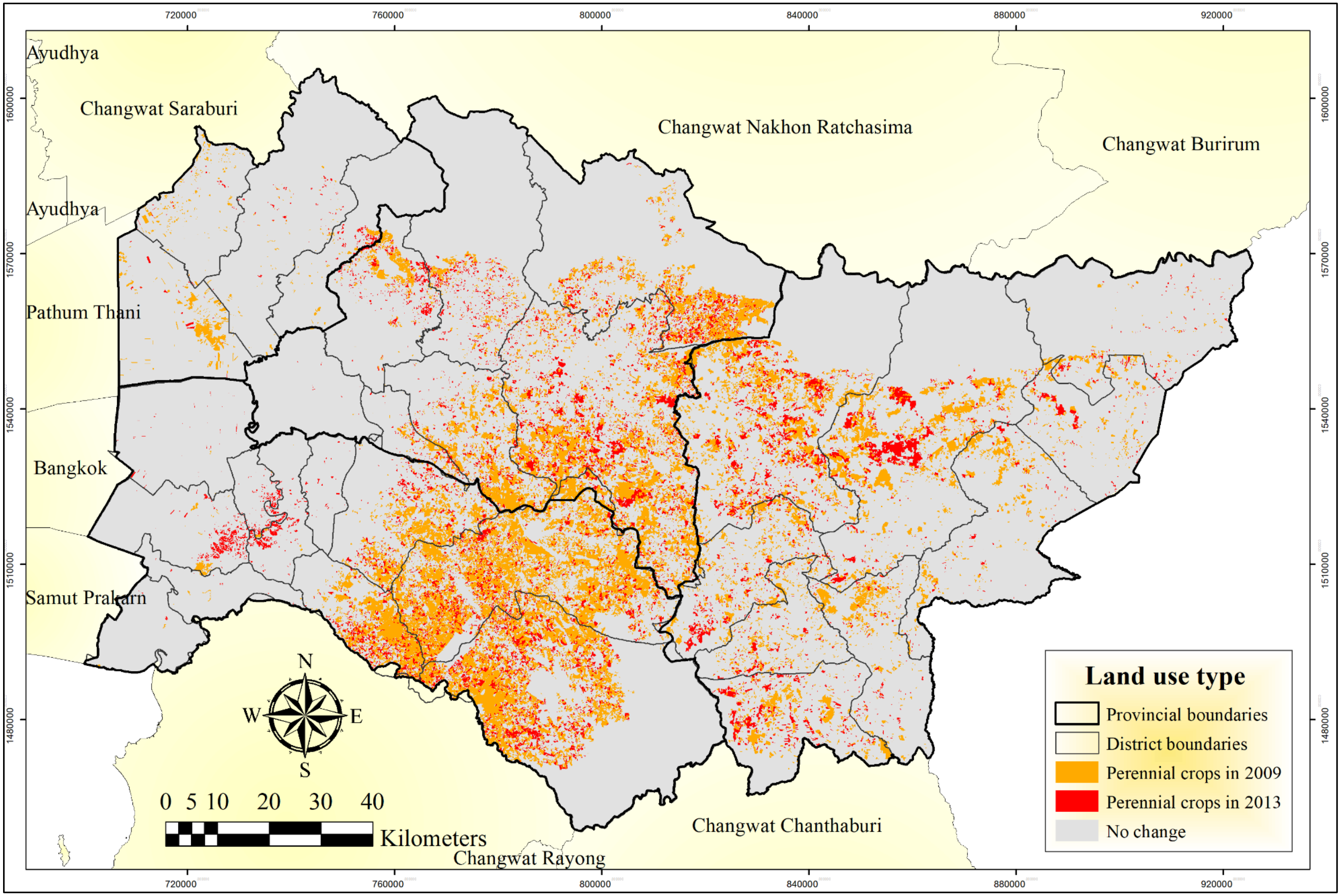

Figure 4.15 : Expansion of perennial crops in the study area compared between 2009 and 2013

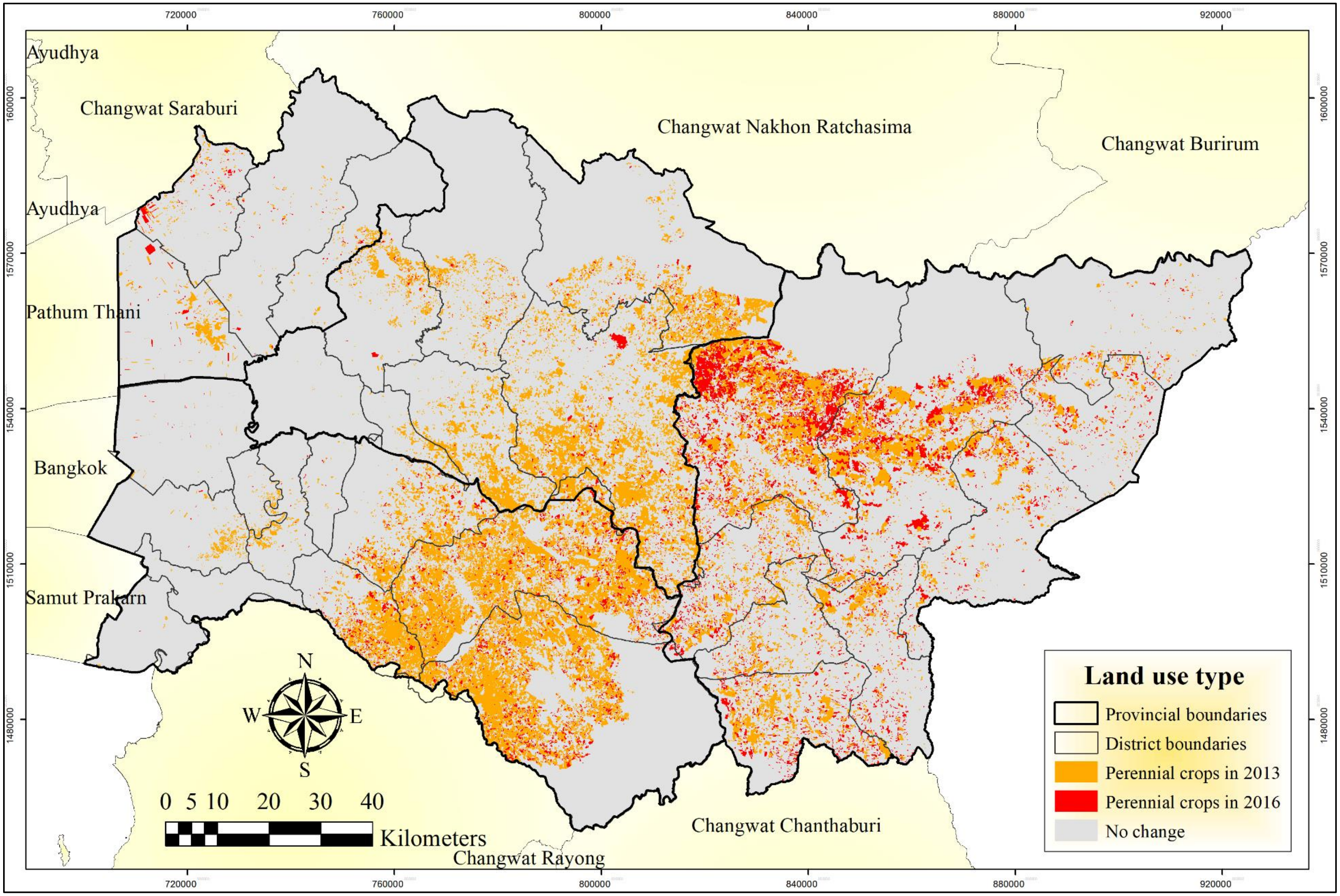

Figure 4.16: Expansion of perennial crops in the study area compared between 2013 and 2016

- **Cultivated area of perennial crops in Bang Pakong river basin**

According to the data of Prachinburi Agricultural Extension Office, the major types of perennial crops in Prachinburi are bamboo, Para rubber tree and oil palm as shown in the Table 4.7 above. The table shows the number of cultivated area separately with three types of perennial crops on each year since 2009 until 2016. Those three types of perennial crops are defined as the economic crops. Therefore, those crops are going to play an important role in Prachinburi province in the future. The area of perennial crops can be separated into each district of 4 provinces as shown in the Appendix.

However, from the Table 4.7**,** I compared the cultivated area of perennial crops in Prachinburi province which are taken from Prachinburi Agricultural Extension Office (OAE) with the data from image classification of Land Development Department (LDD). To match with the classified images from LDD in 5 years period between 2002, 2006, 2009, 2013 and 2016, I decided to select 2013 and 2016 so that the data will be compared exactly in the same year. Yet, the data of OAE does not separate the cultivated areas into each districts in every year. Thus, only 2013 and 2016 will be compared in this case.

As shown in the Table 4.8**,** after comparing with the 2 sources of data from LDD and OAE, it is clearly be seen that the numbers of cultivated area of bamboo, Para rubber tree and oil palm from both offices are totally different.

An incomplete number of crops can be one of the reasons why the numbers of crops from OAE are different from the data of LDD. According to the interview with the officer from OAE, the officer explained that in Prachinburi province, the crop data will be collected only for 12 economic crops; Napee rice and Naprang rice, maize, cassava, pineapple, sugarcane, durian, mangoesteen, rambutan, longon, lychee, oil palm and rubber tree. Most of the numbers of crops they have received are from each District Agricultural Office. The farmers themselves will register and report their type and number of crops to the office but the problem is that not all the farmers will report their crops to the office but it is only the farmers who cultivate economic crops because if they register to the office, they will obtain the support or materials from the government. While other types of crops which are not concluded as an economic crop might not obtain those supports. As a result, this is why the numbers of crops is incomplete.

Moreover, the district officers who in charged in the area cannot survey all the crops himself because of a limitation of the number of officers, there is not enough officer working on this survey work. In some cases, one officer need to in charge at least 2-3 sub-districts. Therefore, he cannot check the areas thoroughly. As a result, it is highly possible that the data of crops is not included for the whole Prachinburi province.

In addition, from my own field survey on October 2017 in Prachinburi province, there are a lot of Eucalyptus crops which is one of the perennial crops but it is not included in the data of OAE. Thus, the data itself might not include every perennial crops in Prachinburi as well.

Table 4.8: The cultivated area of perennial crops in Prachinburi province based on farmers registered in 2009-2017

Year	Farmers registered cultivated area of perennial crops (rai)			
	Bamboo	Para rubber tree	Oil palm	**Total**
2009	42,842	9,029	11,102	62,973
2010	33,140	21,197	4,630	58,967
2011	26,418	21,178	9,739	57,335
2012	27,698	22,588	11,392	61,678
2013	26,482	24,236	15,148	65,866
2014	22,919	34,470	15,446	72,835
2015	22,919	30,252	16,951	70,122
2017	22,919	28,712	16,155	67,786

Table 4.9: Comparing of perennial crops in Prachinburi province Land Development Department and Office of Agricultural Extension.

Districts	Cultivated area of perennial crops from ODD/OAE (rai)			
	2013		2016	
	LDD	OAE	LDD	OAE
Amphoe Ban Srang	223	18	144	183
Amphoe Kabinburi	258,483	20,978	258,477	23,002
Amphoe Muang Prachinburi	25,445	21,379	25,935	18,750
Amphoe Nadi	80,094	17,335	72,506	18,609
Amphoe Prachantakham	23,881	4,564	24,586	5,214
Amphoe Sri Mahosoit	9,018	328	8,128	328
Amphoe Srimahapho	64,624	1,264	59,181	1,427
Total	**461,768**	**65,866**	**448,957**	**67,786**

- **Driver of change of perennial crops**

Perennial crops in the study area based on the recorded statistics of crop cultivation from Regional Office of Agricultural Economics can be categorized into Para rubber tree, bamboo, oil palm and Eucalyptus tree. However, due to the registered of farmer's crops, the farmers will only register with an economic crops which are paddy field, orchard crops (Rambutan, Durian, Mangoesteen, Langsat, Lychee and Longan), Field crops (Casava and Maize), Perennial crops (Para Rubber tree, Bamboo and Oil Palm).

Those crops are the economic crops which the farmers will obtain a support or materials from the government after they registered to the Office of Agricultural in their province. In some cases. For example, Eucalyptus tree, it is cultivated in many parts of the study areas but Eucalyptus tree does not take into an account of all those economic crops above. Eucalyptus tree used to be one of the most impacted tree for environment, especially with soil, water and living things such as animals. It severely damaged with other agriculture productivity because it consumes a lot of water, its root can go down very deep up to 30 feet and it releases some toxic that will damage for environment. Several years ago, the Government encouraged the farmers to cultivate Eucalyptus tree because it can grow very fast and more importantly, to support in paper industries. They supported seeds to the farmers and help the farmers harvesting. Moreover, the guarantee price was quite high at that time. As a result, in Prachinburi province, based on the statistics of farmer's registered in 2009 and 2010, the farmers cultivated their Eucalyptus crops over 196,180 rai (31,388 ha).

However, based on the statistics of OAE, after in the year 2010, there was no more statistics on Eucalyptus tree. Regarding to the interview, the farmers did not registered for their Eucalyptus crops anymore because they thought that Eucalyptus tree is not included as one of an economic crops, then they will not obtain any benefits from registering Eucalyptus tree and changed to be more interested in other economic crops instead.

According to the report of Regional Office of Agricultural Economics about economic crops in 2014-2017, the report shows that there is more farmers registered perennial crops in the study area. In Nakhon Nayok province, the farmers cultivated more crops of perennial since 2013. There is an increasing of perennial crops especially in Muang District. In Prachinburi province, the farmers in Bang Sang, Nadi and Kabinburi Districts registered more for oil palm.

In terms of the driver of change of perennial crops (Para rubber tree, bamboo and oil palm) in the study area which included 4 provinces (Nakhon Nayok, Prachinburi, Sa Kaew and Chachoengsao provinces). As seen in the Figure 4.14, 4.15, and 4.16, Perennial crops have been expanded since 2006 until 2016. Regarding to the Regional Irrigation Office, the main change of perennial crops in Prachinburi, Sa Kaew and Chachoengsao provinces are due to Eucalyptus tree instead of Para rubber or oil palm because recently, the price of Para rubber is decreasing. In terms of oil palm, even though, it is increasing but it is not expanded in the large area. Therefore, Eucalyptus tree is the most possible crops that has been increasing instead because the farmers might cultivate the Eucalyptus tree to support the paper's industries. Apart from consuming water from the irrigation area, rainfall is another water source of them.

- **Aquaculture land**

In terms of expansion of aquaculture land, From the Figure4.18-4.22. On the other hand, aquaculture land is not expanded throughout the basin compared with the expansion of perennial crops. However, aquaculture land in the year 2002, was found in some part of Chachoengsao, prachinburi and Nakhon Nayok provinces. Especially at the lowest part of Chachoengsao province where it is nearby Samut Prakarn province. That area is the densest area of aquaculture land because it is the most suitable of land. Most of the aquaculture land located nearby the Bang Pakong River which discharges into the Gulf of Thailand.

Until in the year 2006, the expansion of aquaculture is expanded differently, it encroached more into inland. It expanded in the middle part of Chaochoengsao province instead (Ban Phoe, Bang Khla and Bang Pakong districts). In Prachinburi province, a concentration of aquaculture is in Ban Sang District. For Nakhon Nayok provinces is in Muang and Ongkhalak District. However, in Sra kaeo province, aquaculture is very less proportion as shown in the Table 4.9 because of an unsuitable geography.

- **Driver of change of fish and shrimp production**

The salinity level in land leads the farmers to do fish and shrimp production as the water is brackish which is suitable especially with shrimp. However, for fishes, if the water is not too saline, they can survive in the brackish water as well. Therefore, many farmers in the study area can put both of fishes and shrimps in the same pond.

For water needs of fish and shrimp production, the farmers need to put the water into the ponds which have various size of pond. Moreover, in one crop of raising fish and shrimp, after the fishes and shrimps are harvested, in the same time water is drained out. Then the farmers will pump the water from canal or the river directly into their ponds to prepare raising the new crop of fish and shrimp.

The first obviously change of fish and shrimp production area is in the lower part of Chachoengsao Province (Bang Pakong district) as seen in the Figure 4.17 , in the year 2006 to 2009, fish and shrimp farming expanded very strong then in the next 4 years later (in 2013-2016) the farming became less strong. According to the interview with Prachinburi Fisheries Office, most of fish and shrimp farmers in Prachinburi (Ban Sang District) and Nakhon Nayok (Ongkarak and Muang Districts) are originally from Samut Prakarn province (Nong Ngu Hao District) then moved to do fish and shrimp production to Prachinburi and Nakhon Nayok due to a suitable geography as it has Bang Pakong and Prachinburi rivers flow through. Thus, selecting a suitable areas for fish and shrimp farming is needed to relate with a good condition of sources of water. As it is be seen in the following figures of Expansion of aquaculture land, expansion of fish and shrimp farming is along the rivers or inside an irrigation area.

In the year 2002, fish and shrimp farmers moved to do fish and shrimp production in the upper areas due to a good condition of sources of water. Then in the year 2006 – 2009, as it is seen in the following figures, fish and shrimp farmers expanded very fast in Prachinburi and Nakhon Nayok provinces. At that time, fish and shrimp farming were very famous because fish and shrimp got high prices. After that more farmers invested in fish and shrimp production until it expanded very fast all the areas. After 2009, fish and shrimp farming cannot expand more as there is no more areas to dig the ponds.

Another major change of fish and shrimp production in the study area is relevant to an expropriation of land from the project of Suvarnabhumi Airport in the year 2011.
Regarding to the point of view of Prachinburi Fisheries Office, a decreasing of fish and shrimp in the lower area of Chachoengsao Province in Bang Pakong district related to the expropriation of land to start the project of Suvarnabhumi Airport in the year 2011. From the Figure 4.18, fish and shrimp production in the lower area were mostly disappeared while there were a huge increasing of fish and shrimp farming in the middle and upper area instead. The Office of Fisheries explained that most farmers from the lower area moved to do fish and shrimp farming in Prachinburi and Nakhon Nayok because of a good condition of water resources.

Besides, regarding to the study of Agricultural dynamics in the Bang Pakong River (Léna AGUILHON, 2017), the factors of change for fish and shrimp production are lack of savings and the impossibility for the farmers to invest. Fish and shrimp production is quite costly, it needs to invest for labors and several inputs such as machine (water pumping, oxygen paddle and maintenance), fish and shrimp foods and products.

Secondly, lack of knowledge is risky for the farmers because the production requires skills. Also, if the farmers do not own their own land, they have to rent the land of someone else. Or in some cases, the farmers do not want to do fish and shrimp farming in the first place if they do not own their own land because they do not want to invest on someone else land.

Finally, lack of water resources. As mentioned above about the water need for fish and shrimp production, it needs a lot more water than rice paddy. In one crop/season of raising fish and shrimp, it needs to fill water in the pond several times. After the fishes and shrimps are harvested, in the same time water is drained out and the farmers will fill the water to their ponds again. The main water sources of fish and shrimp are from the canal and river. Most of them raise fish and shrimp in an irrigation area. Thus, they pump the water from the canal where connect to Prachinburi river. However, if the water is too saline (over 1 ppm), RID will close ¾ of the gate in order to block saline water into the canal because those water will be effected with agriculture crops. For shrimps, it can survive in the brackish water but it will be a huge impact on fishes.

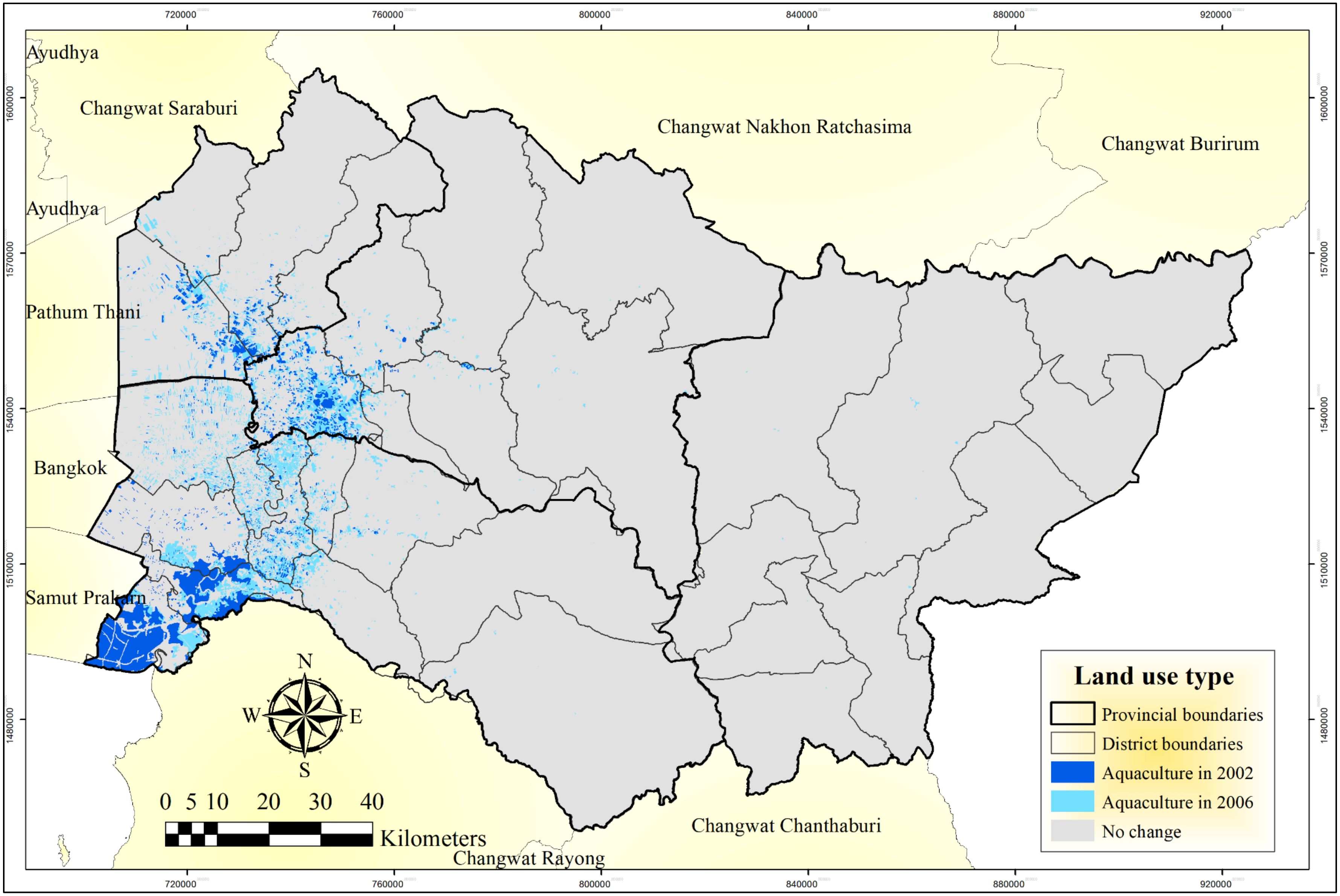

Figure 4.17: Expansion of aquaculture land in the study area compared between 2002 and 2006

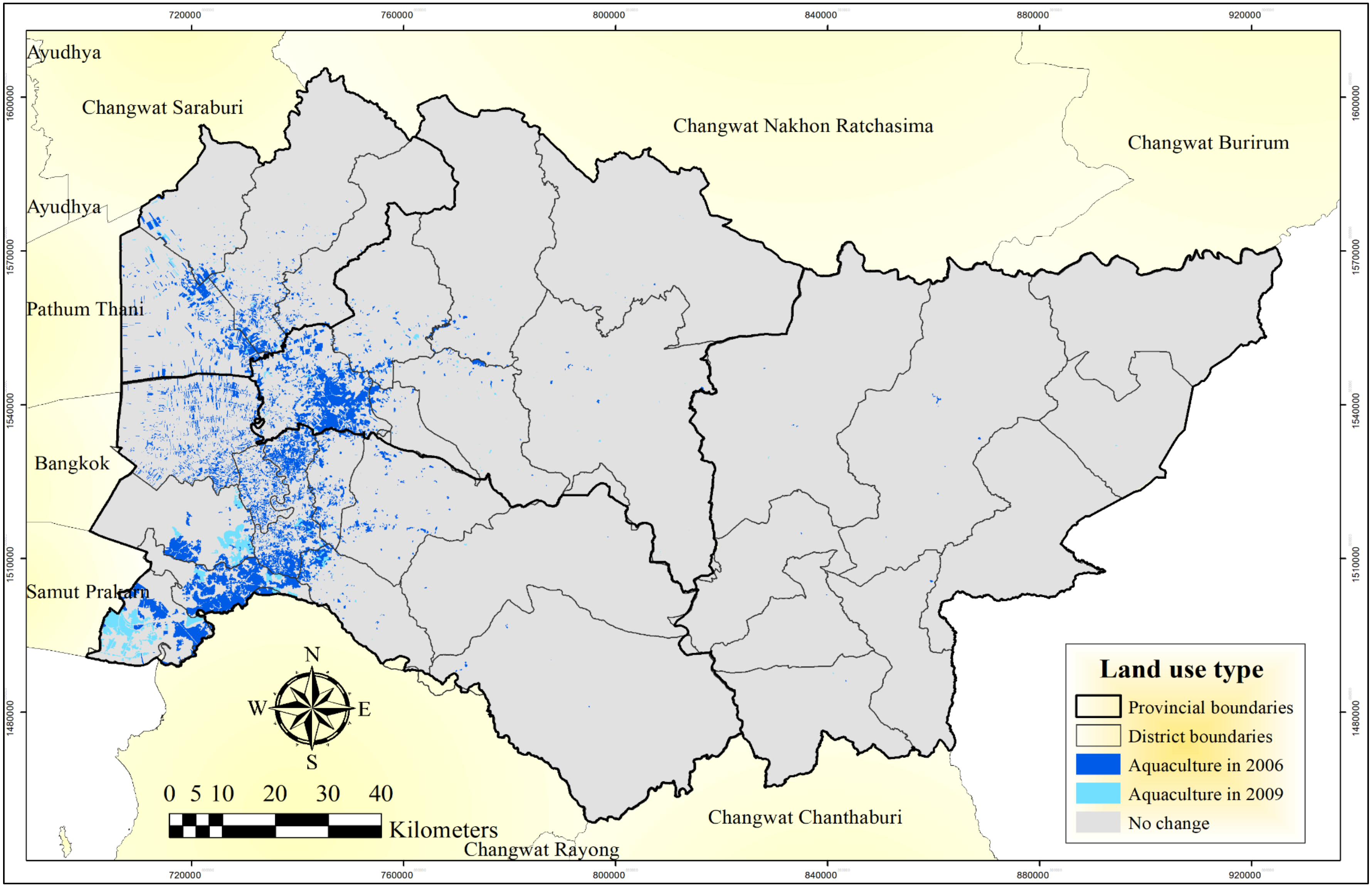

Figure 4.18: Expansion of aquaculture land in the study area compared between 2006 and 2009

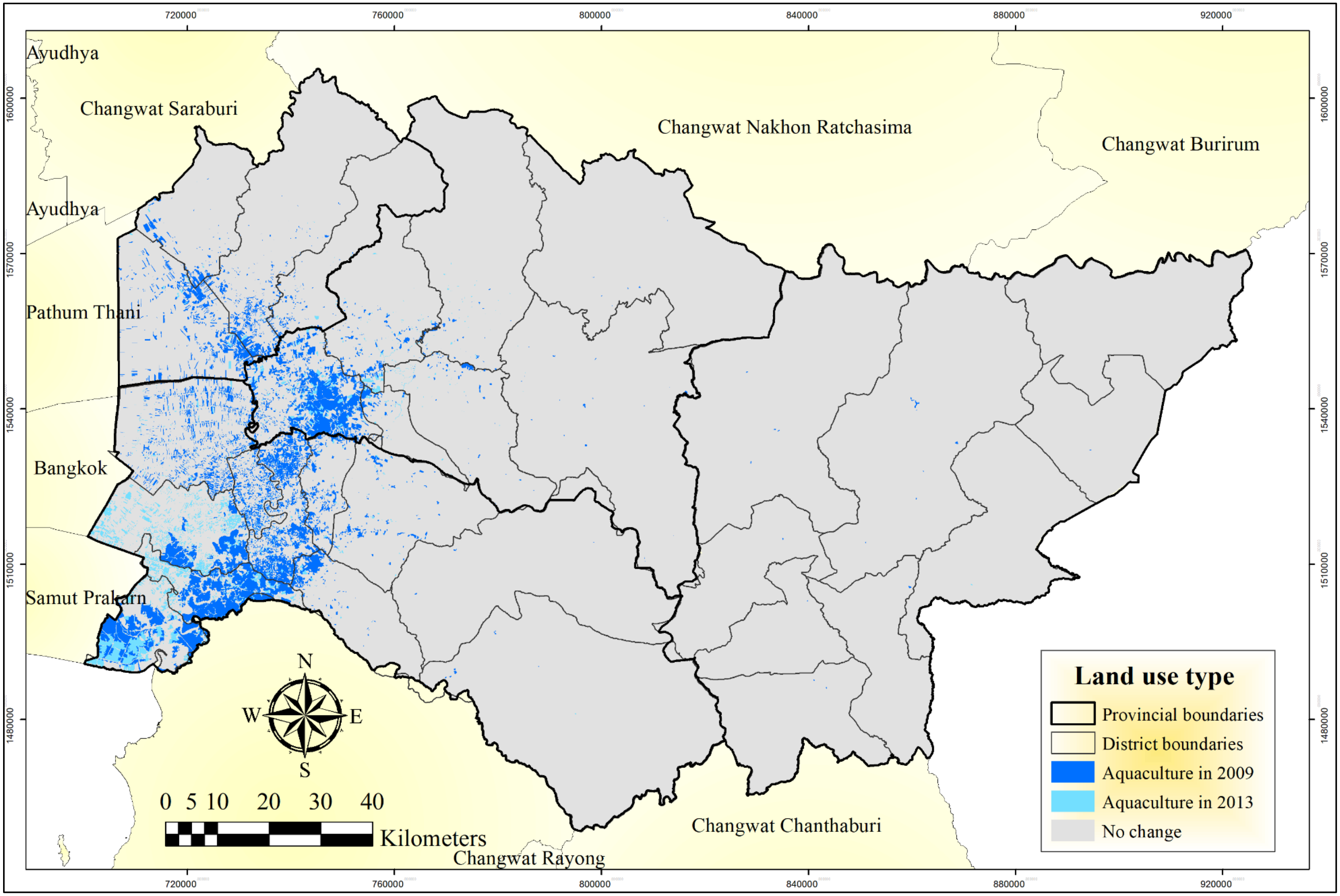

Figure 4.19: Expansion of aquaculture land in the study area compared between 2009 and 2013

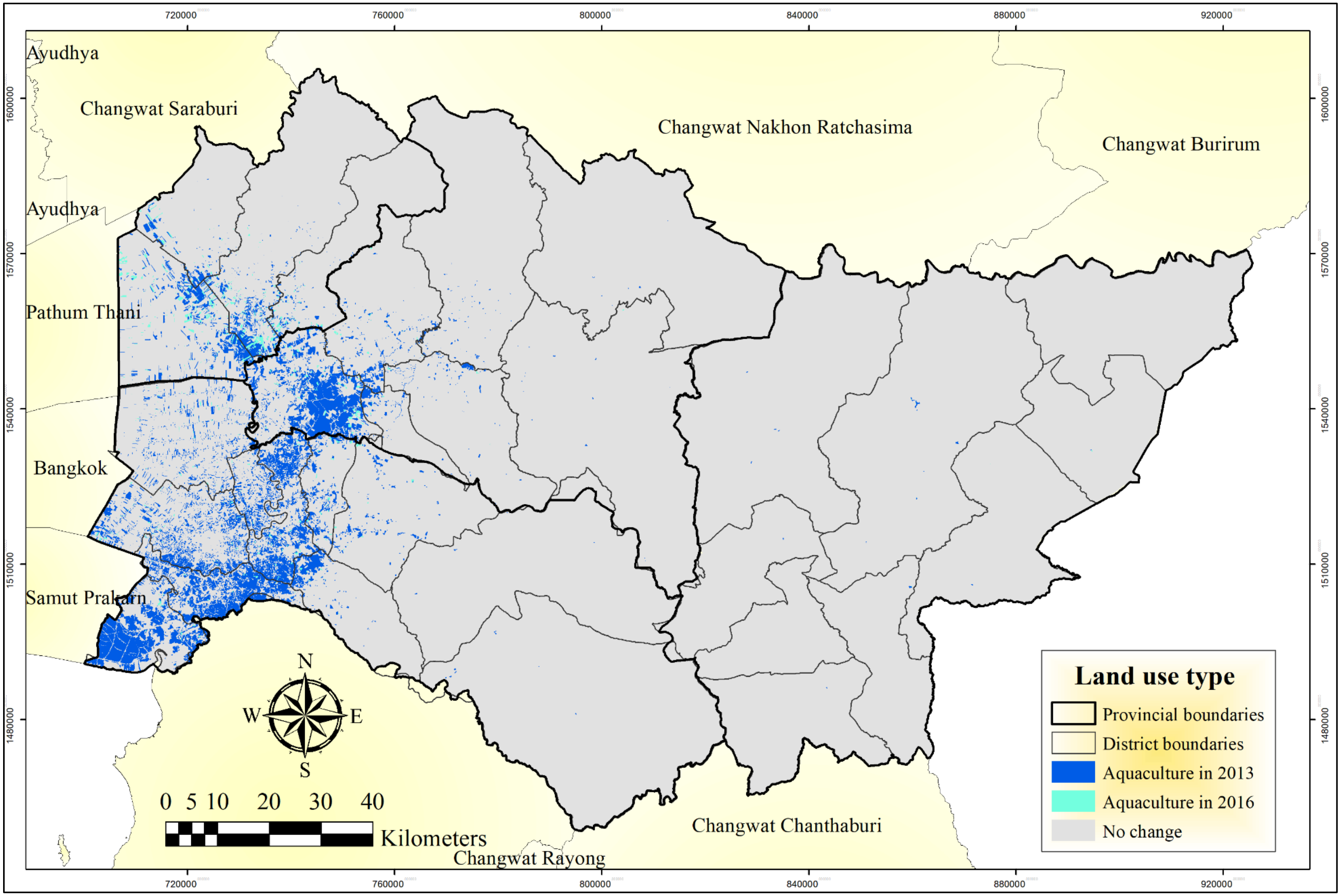

Figure 4.20: Expansion of aquaculture land in the study area compared between 2013 and 2016

4.2.3 Forest land

Forest land in the study area has slightly decreased during this 14 years period. It occupied averagely 460,673 hectare or 24% of all land use types. Forest land occupied 474,689 hectare or 25% in 2002 and slightly decreased by 24%, 23%, 24% and 24% in 2006, 2009, 2013 and 2016, respectively. Forest land are classified into 7 types which are agro-forestry, deciduous forest, evergreen forest, forest plantation, mangrove forest, dense forest and disturbed forest. Forest land in the study area is quite rich and dense. It is not much changed because the forest is a conservative zone and not allowed to encroach or settle down as it located nearby National Park.

4.2.4 Miscellaneous land

Miscellaneous land in the study area occupied averagely 55,977 hectare or 3% of all land use types. Miscellaneous land are classified into 9 types of land which are marsh and swamp, miscellaneous land, garbage dump, mine, pit, other miscellaneous land, rangeland and salt flat. This miscellaneous can be diversely turned into other land uses type especially agriculture and industrial land as it is a bare land. In the study area, in the last year 2017, miscellaneous land rapidly decreased from the previous years because it has been changed into urban land use and pond.

4.2.5 Urban land

Urban land in the study area occupied averagely 137,725 hectare or 7% of all land use types. Urban land are classified into 7 types of land which are city (included town and commercial), village, institutional land, communication and utility, industrial land, other built-up land and golf course. Village, institutional land and industrial land occupied the most proportion of urban land during 2013 to 2016. As shown in the table 4.11, village and institutional land steadily changed. Meanwhile, industrial land increased from 2013 by 9% to 11% in 2016. The most occupied of urban land in the study area is village. Over 60% in 2013 and 2016, village is the most proportion of urban land use following with institutional land such as school, hospital, temple or offices. Industrial land is also much occupied especially in Chachoengsao and Prachinburi province where located many industrial estate zones.

Table 4.10: Coverage area of each type of urban land.

Type of urban land	2013 (ha)	%	2016 (ha)	%
City, Town, Commercial	4,878	4	5,570	4
Village	90,194	65	89,479	63
Institutional land	19,341	14	20,039	14
Communication and utility	6,877	5	6,969	5
Industrial land	12,834	9	15,559	11
Other built-up land	1,364	1	1,743	1
Golf course	2,439	2	2,469	2
Total	137,927	100	141,829	100

4.3 Water pumping assessment

In this objective, the assessment of water pumping will be assessed for dry season crops (November- April) which is irrigated water in the dry season.

The agricultural crops that are mentioned earlier in the study are paddy field, field crop, perennial crops, orchard and including of aquaculture. However, only paddy field and aquaculture will be assessed its water requirement as it irrigated crops while other crop activities are rainfed crops. Consequently, this study is focused on water requirement assessment for paddy field and fish and shrimp farming.

Basically, the assessment of water pumping can be separated into 2 activities which is cultivation activities and non-cultivation activities. Assessing the water in order to plan the water use, especially in the dry season can effectively manage and stock the water for agricultural purposes throughout the year.

4.3.1 Water pumping for non-cultivation activities

In terms of non-cultivation activities. For example, water pumping for drinking water purpose, industrial purpose or livestock purpose. In this study, the water sectors which are non-cultivation purposes are focused on drinking water sector and industrial sector.

For non-cultivation activities, particularly in industrial sector which generally situated as an industrial zone, mainly in Chachoengsao and Prachinburi provinces. Assessing water pumping for industrial sector hardly achieves the specific amount of water pumping because they do not measure the amount of water they pumped. There are two cases of pumping water for industrial sector; firstly, they pump the water directly from the river and secondly, they will buy the water from the big Water Company which are the 2 big Water Company in the basin who support the water for industries. Asking for the specific number of water they pumped is quite difficult in this case due to a commercial limitation and most of big Water Company keep it as a privacy.

Another water sector is drinking water sector. In this study area, Provincial Waterworks Authority (PWA) and the local waterworks authorities are in charge of water supply and drinking water use. Based on an interview with the officers from PWA in Prachinburi province, 60% of water supply and drinking water in the province is responsible by PWA. Another 30-40% is in charge by the local waterworks authorities in each village.

For water supply, they can measure the amount of water very accurately because they pump the water from the river and produce it daily before they allocate to each household. During their processing, it is needed to measure and record every litre of water they pumped.

Therefore, for industrial sector and drinking water sector, this study will be based on an interview of the relevant organizations and the number of water pumping per year is received from the previous studies of RID reports as shown in the Table 4.12

Although, domestic use or drinking water activity and industrial activity are important in the basin, irrigation activities is also the most used of water in the basin. The water is pumped from the main river and irrigated into irrigation canals for agricultural purposes.

Table 4.11: The Amount of water pumping for non-cultivation activities in the basin
Source: Hydro and Agro Informatics Institute (HAII), 2012

Non-cultivation activities	The amount of water pumping (Million Cubic Metre/Year)
1. Irrigation	2,718.77
2. Domestic use/drinking water	70.33
3. Industry	18.70
4. Livestock	5.10
5. Tourism	1.49

4.3.2 Water pumping for cultivation activities

The water pumping for crops are relevant to the water requirement of each crops because each crops requires different quantity of water depending on the different species of crops, size of crop areas and the period of growing crop.

- **Crop water requirement**

Assessment of water requirement for each crop can be assessed in two major ways: by a direct measurement using equipments and based on a climatic data or Reference Crop Evapotranspiration which is calculated from these following equation: Modified Penman, E–pan, Penman Monteith, Blaney Criddle, Thornthwaite, Hargreaves and Radiation.

In this study, Penman-Monteith equation will be conducted because this method is a standard equation for crop water requirement in Thailand in the case of using a climatic data.

Based on Penman-Monteith method, to find out the crop evapotranspiration (ETc), Kc coefficient incorporates crop characteristics and averaged effects of evaporation from the soil (FAO, 2013). It needs to consider carefully that each crop has different Kc coefficient. According to Penman-Monteith equation, to assess water requirement of crops will be based on this following equation:

$$ETc = Kc * ETo$$

ETo = Potential Evapotranspiration (mm./day)
ETc= Water consumption of crop plant (mm./day)
Kc = Crop Coefficient

Kc value will be varied with the specific crop characteristics, in one crop, the Kc value varies throughout its growing season. Kc will be changed the value from the crops' sowing till its harvest. For example, rice paddy is normally grown since in 13 weeks, each week has different Kc based on its growing period. Moreover, each rice species also have different Kc.

The table 4.13**,** shows the Kc of Korko rice, or the rice that is a major species cultivating in the basin. It is a second rice crop or is locally called Nabrang rice. Korko rice is identified as the non-photosensitive rice. As this result, Korko rice can be cultivated throughout the year but the farmers commonly cultivate in the dry season because it gives better productivities in the dry season. The Kc of Korko rice varies from the first week of sowing until the 13th week of harvest. As shown in the table 4.12, the 6th – 7th week of rice is the highest rice Kc, it can be explained that in the middle of growing period of rice (6th-7th week), rice needs the most quantity of water.

Another table 4.14 below**,** is shown the Kc of fish and shrimp farming which is different from Kc of rice because while Kc of rice varies in 13 week, but fish and shrimp' Kc varies in monthly for one year. In this case, due to one crop/ cycle of fish and shrimp farming is normally cultivated between 9-12 months, the farmers will raise three fish and shrimp cycles, once they have harvested their productivity then they immediately add the second or third cycle of fish and shrimp. The water is drained out at the same time fish and shrimp are harvested (AGUILHON, 2017). The Kc of fish and shrimp is all stable as it is a pond, the farmers need to fill the same level of water throughout the cycle.

Table 4.12 : Crop Coefficient (Kc) of Korko rice
Source: RID, 2012

Crop Coefficient (Kc)for Korko rice	
Week	KC for Korko rice
1	1.03
2	1.07
3	1.12
4	1.29
5	1.38
6	1.45
7	1.5
8	1.48
9	1.42
10	1.34
11	1.23
12	0.94
13	0.86
Average	1.24

Table 4.13 : Crop Coefficient (Kc) of fish and shrimp farming
Source: RID, 2012

Crop Coefficient (Kc)for fish and shrimp farming	
Monthly	KC for fish and shrimp farming
1	1.0
2	1.0
3	1.0
4	1.0
5	1.0
6	1.0
7	1.0
8	1.0
9	1.0
10	1.0
11	1.0
12	1.0
Average	1.0

For Eto (Reference crop Evapotransiration) is the reference index of climatic demand. The Eto also varies based on each provincial meteo station. In this study area, there are 4 provinces in Thailand where it covers for the whole basin, the Eto reference is based on the meteo station from Prachinburi station, Chacheongsao station and Sa kaew station as Nakhon Nayok refers with the same Eto of Prachinburi station. The Eto reference are measured from Meteorological Department, using the climatic data of 30 years in this study (1981-2010) as shown in the table 4.15.

Table 4.14: Reference Evapotransiration (ETo) based on provincial meteo station
Source : RID, 2011

Reference Evapotransiration ETo according Penman-Monteith				
Month	Chacheongsao	Prachinburi	Nakhon Nayok	Sa Keaw
January	3.85	3.87	3.87	3.96
February	3.83	4.04	4.04	4.46
March	4.19	4.30	4.30	4.67
April	4.31	4.62	4.62	4.66
May	3.86	3.98	3.98	3.96
June	3.52	3.50	3.50	3.88
July	3.46	3.45	3.45	3.45
August	3.46	3.43	3.43	3.40
September	3.26	3.27	3.27	3.24
October	3.33	3.79	3.79	3.64
November	3.47	4.10	4.10	3.92
December	3.51	4.07	4.07	3.78

The Etc or crop water needs will be calculated by multiplying the Potential Evapotranspiration (Eto) with Crop Coefficient (Kc) and finally can assess the water requirement of crops.

4.3.3 Water requirement of irrigated rice

The major agricultural activities in the study are categorized into 5 activities including of aquaculture land which is fish and shrimp farming.

The Table 4.16 below shows the surface area of each crops activities in the basin in the past 10 years. Assessing water requirement for each crop needs to be concerned about its surface area. Size of crops is one of the major factors that is directly related to the quantity of water use for each crop. This study will take only paddy field and fish and shrimp farming into account as these crops irrigated water in the dry season while other crop activities are rainfed crops.

Table 4.15 surface area of agriculture crops in the basin from 2006-2016

Crop area	Year			
	2006 (ha)	2009(ha)	2013(ha)	2016(ha)
Paddy field	527,958	519,436	486,409	466,791
Field crop	362,529	333,878	315,785	294,966
Perennial	174,663	214,634	266,963	301,090
Orchard	56,174	44,264	38,032	41,210
Aquaculture land	67,620	76,314	83,326	87,871

For paddy field, the classified images from satellite imagery in 2006-2016 are classified the rice area for the whole rice crops which are the area of rice in the dry season or irrigated rice and included rainfed rice or non-irrigated rice as well. As concerning only in the dry season, it is needed to separate the period of rice season. The Table 4.16 is separated the surface area of rice into irrigated rice and non-irrigated rice.

Table 4.16: surface area of irrigated and non-irrigated rice in the basin from 2006-2016

Year	Irrigated area (ha)	Non-irrigated area(ha)
2006	276,948	251,469
2009	272,081	247,355
2013	258,136	228,693
2016	252,998	214,343

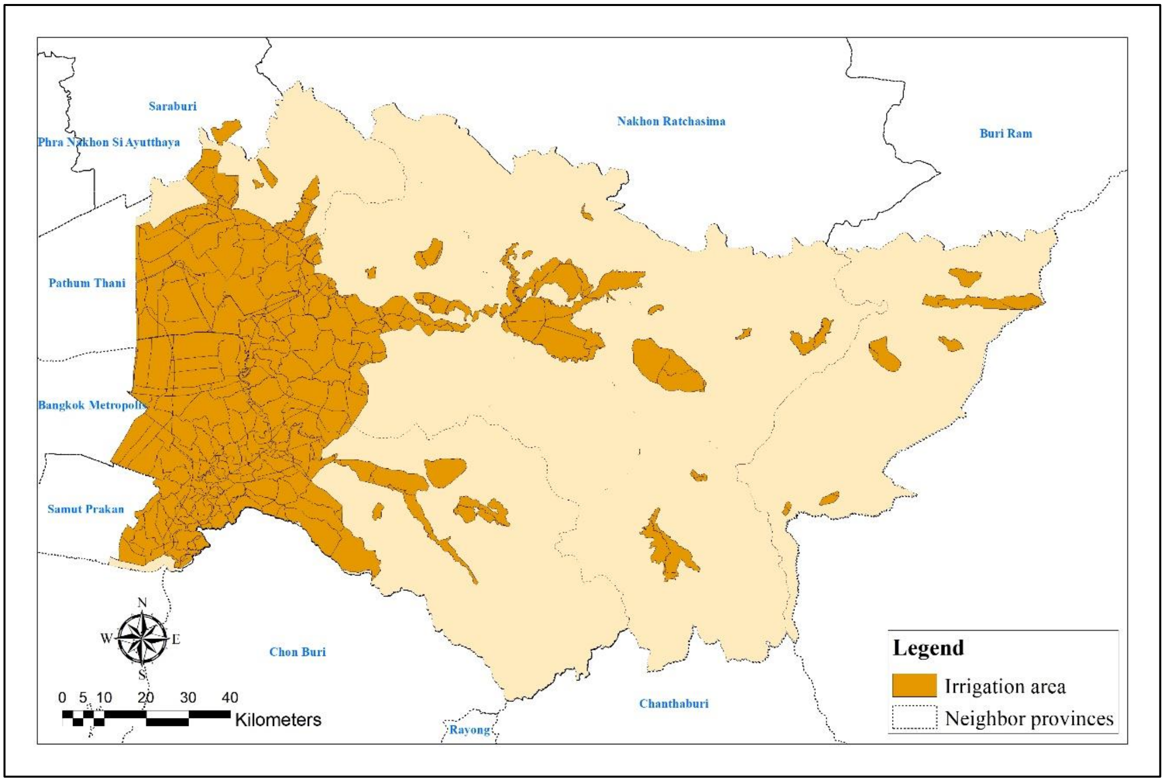

Figure 4.21 : Irrigated boundaries in Bang Pakong river basin.

The Figure 4.21 above shows the map of irrigated boundaries in the basin. The irrigated area has approximately 530,243 ha from the total area 1,916,747 ha of the whole basin. The irrigated area or the zone of agriculture crops was planned and manage the water allocation by RID.

The differentiation between irrigate and non-irrigated area can be achieved by input the shapefile data of irrigated area from DWR office. Then the boundary shapefile of the whole basin and overlay it with the irrigated area. In the case of irrigated rice and non-irrigated rice (Table 4.16), I input the shapefile of rice for each year (2006-2016) to overlay the rice area with the irrigated area. Thus, the area of rice which is inside the irrigated area can be the irrigated rice while the rice which is outside the irrigated area is non-irrigated rice or rainfed rice.

The Figure 4.22 demonstrates a different period of rice. Firstly, irrigated rice or the rice in the dry season. From 2006-2016, the surface area of irrigated rice has been slightly decreased from 276,948 ha to 252,998 ha. Most of irrigated rice according to the map in Figure 4.22 are still in the same area, the area of rice does not change much because the farmers need to choose the cultivated rice crops nearby the irrigated canals.

In one hand, non-irrigated rice also has been decreased its surface area from 251,469 ha to 214,343 ha. However, this non-irrigated rice in Figure 4.23 does not affect much in terms of water resources in the basin as it is no need to irrigate water but depends on rainfall.

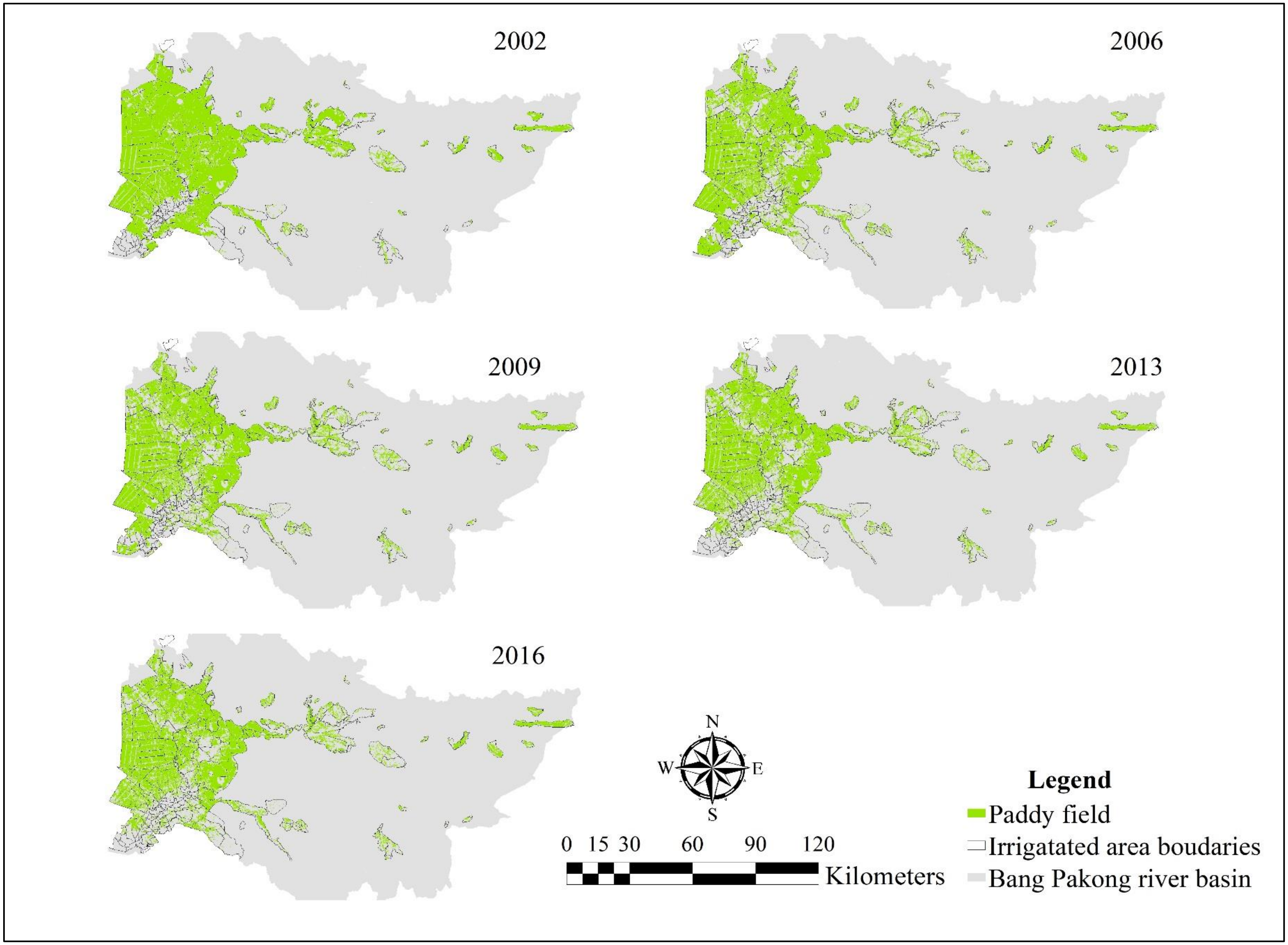

Figure 4.22 : Irrigated rice in Bang Pakong basin in 2002-2016

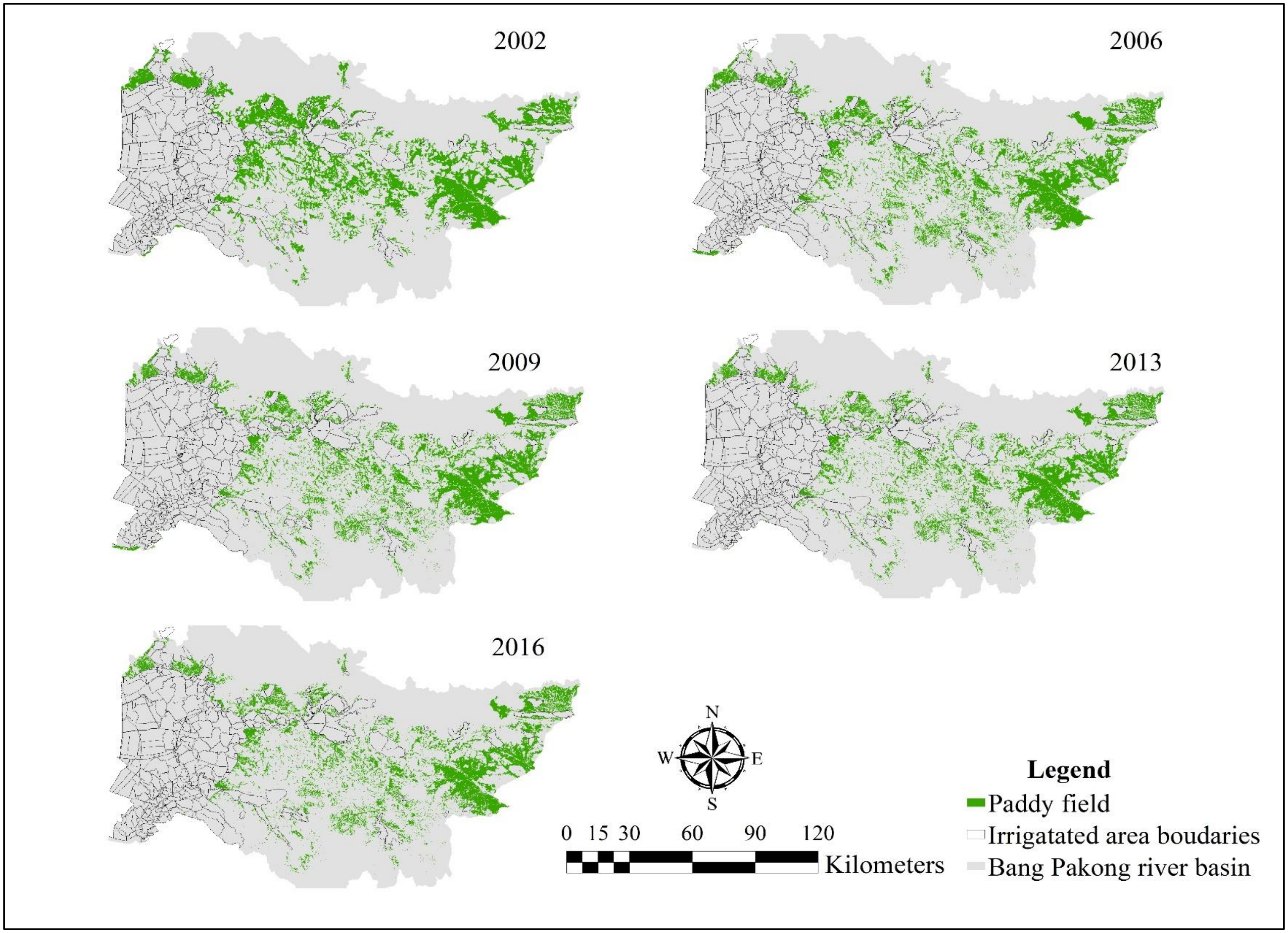

Figure 4.23 : Non-irrigated rice in Bang Pakong basin in 2002-2016

For calculating the water requirement for irrigated rice, it is needed to calculate the water use per hectare. Even though the classified images from LDD can separate a roughly of irrigated and non-irrigated rice by overlaying it with irrigated boundaries, it still need to calculate the area of dry season rice. In this case, this study used the classified images that is focused only on dry season rice from The Geo-Informatics and Space Technology Development Agency (GISTDA) as they monitored for paddy field in Thailand in the past 4 years.

Table 4.17 : The surface area of dry season rice from November to April in 2015-2017

Month	Year		
	2015 (ha)	2016(ha)	2017(ha)
November	149,747.14	111,464.70	127,760.18
December	58,830.23	130,104.52	180,034.91
January	96,209.08	54,552.49	101,861.28
February	19,852.22	17,394.56	42,433.73
March	10,639.87	2,025.64	18,775.11
April	13,574.53	2,332.99	14,752.45
Total	348,853.06	317,874.91	485,617.65

The Table 4.18 is the surface area of dry season rice in November to April as it is the period that has the least rainfall. This surface area is taken from the classified images by GISTDA. In each month, there are 2 starting dates, first starting date is in every 15th day and second is the end of the every month. To assess the water requirement of dry season rice in a monthly basis, I multiplied these surface areas with the relevant values of Kc of rice and reference ETo.

The Etc of dry season rice is calculated by multiplying the Kc value (Korko Kc), for Eto, the reference Eto needs to be relevant to each province. Finally, the crop water needs (Etc) of 4 provinces in the basin will be combined together as I would not like to separate the areas into provincial scale but calculate as a basin scale instead as shown in the Table 4.17– Table 4.20.

Each table (Table 4.19-4.22) demonstrates first the starting date of rice, according to GISTDA classified images, they updated the data of dry season rice twice a month (day 15th and 30th). A horizontal row in the table is Eto (reference crop evapotranspiration) in different provincial meteo station that is the climatic data on 30 years period taken from the meteorological department of Thailand. In each month, the Eto value is also different. After preparing every needed value, use Kc for rice and multiply it with Eto value.

Table 4.18: Etc of dry season rice in Prachinburi province.

Starting date	Reference ETo of Prachinburi Station/Month														
	3.79	4.1	4.07	3.87	4.04	4.3	4.62	3.98	3.5	3.45	3.43	3.27	3.79	4.1	4.07
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
15/11		69.45	170.70	163.43	99.22	48.07									
30/11		4.22	146.76	174.50	123.58	103.54									
15/12			73.14	162.31	156.87	120.23	51.65								
31/12			4.19	139.55	164.95	149.86	111.25								
15/1				69.54	151.26	186.32	125.20	47.92							
31/1				3.99	128.96	193.37	157.03	99.26							
15/2					59.23	175.23	194.50	112.75	42.14						
28/2					4.16	155.06	201.76	134.25	78.26						
15/3						77.27	186.83	170.30	92.26	35.60					
31/3						4.43	160.22	179.30	115.05	80.11					
15/4							77.85	165.41	145.46	95.19	35.40				
30/4							4.76	143.52	152.85	116.37	76.69				

Table 4.19 : Etc of dry season rice in Chachoengsao province.

Starting date	Reference ETo of Chachoengsao Station/Month														
	3.33	3.47	3.51	3.85	3.83	4.19	4.31	3.86	3.52	3.46	3.46	3.26	3.33	3.47	3.51
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
15/11		58.78	147.21	162.59	94.06	46.84									
30/11		3.57	126.57	173.60	117.16	100.90	0.00								
15/12			63.07	161.47	148.72	117.15	48.19								
31/12			3.62	138.83	156.38	146.02	103.78								
15/1				69.18	143.40	181.55	116.80	46.47							
31/1				3.97	122.25	188.42	146.50	96.27							
15/2					56.15	170.74	181.45	109.35	42.38						
28/2					3.94	151.09	188.22	130.20	78.71						
15/3						75.29	174.30	165.17	92.79	35.71					
31/3						4.32	149.47	173.89	115.70	80.34					
15/4							72.62	160.42	146.29	95.46	35.71				
30/4							4.44	139.19	153.72	116.71	77.37				

Table 4.20: Etc of dry season rice in Sa Kaew province.

Starting date	Reference ETo of Sa Kaew Station/Month														
	3.64	3.92	3.78	3.96	4.46	4.67	4.66	3.96	3.88	3.45	3.4	3.24	3.64	3.92	3.78
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
15/11		66.40	158.53	167.23	109.54	52.21									
30/11		4.04	136.31	178.56	136.43	112.45									
15/12			67.93	166.08	173.18	130.57	52.10								
31/12			3.89	142.80	182.10	162.75	112.21								
15/1				71.16	166.98	202.35	126.29	47.68							
31/1				4.08	142.36	210.01	158.39	98.76							
15/2					65.38	190.30	196.19	112.19	46.72						
28/2					4.59	168.40	203.50	133.57	86.76						
15/3						83.92	188.45	169.45	102.28	35.60					
31/3						4.81	161.61	178.40	127.54	80.11					
15/4							78.52	164.58	161.25	95.19	35.09				
30/4							4.80	142.80	169.44	116.37	76.02				

Table 4.21: Etc of dry season rice in NaKhon Nayok province.

Starting date	Reference ETo of NaKhon Nayok Station/Month														
	3.79	4.1	4.07	3.87	4.04	4.3	4.62	3.98	3.5	3.45	3.43	3.27	3.79	4.1	4.07
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
15/11		69.45	170.70	163.43	99.22	48.07									
30/11		4.22	146.76	174.50	123.58	103.54									
15/12			73.14	162.31	156.87	120.23	51.65								
31/12			4.19	139.55	164.95	149.86	111.25								
15/1				69.54	151.26	186.32	125.20	47.92							
31/1				3.99	128.96	193.37	157.03	99.26							
15/2					59.23	175.23	194.50	112.75	42.14						
28/2					4.16	155.06	201.76	134.25	78.26						
15/3						77.27	186.83	170.30	92.26	35.60					
31/3						4.43	160.22	179.30	115.05	80.11					
15/4							77.85	165.41	145.46	95.19	35.40				
30/4							4.76	143.52	152.85	116.37	76.69				

Table 4.22: Water requirement of dry season rice

Month	Year		
	2015 (m3)	2016(m3)	2017(m3)
November	790,112,675.20	597,942,569.05	679,676,605.81
December	324,941,145.81	718,390,371.12	969,814,387.30
January	552,165,929.44	308,163,232.17	557,946,770.35
February	115,647,436.97	100,098,529.85	238,448,870.50
March	56,617,912.04	11,041,566.81	101,763,764.66
April	68,598,510.64	11,697,128.68	76,357,189.40
Total	1,908,083,610.10	1,747,333,397.68	2,624,007,588.02

The period between November – April is conducted to assess the water requirement as this period has the average lowest rainfall throughout the year based on meteorological report.

The table 4.22 above shows the water requirement for dry season rice in November – April, after multiplying the crop water needs (Etc) with the surface area of rice in the earlier table 4.16.

Therefore, dry season rice needs water approximately 5,500 m3 per hectare. As this result, the water requirement for irrigated rice is as following:

Table 4.23 : water requirement for irrigated rice in 2006-2016

Year	Irrigated area (ha)	Water requirement for irrigated rice (m3)
2006	276,948	1,523,214,261
2009	272,081	1,496,445,615
2013	258,136	1,419,749,425
2016	252,998	1,391,489,008

With an average 5,500 m3/ha of water needs of dry season rice, it needed to multiply with the surface area of irrigated rice to find out the water requirement or the amount of water that should be pumped for irrigated rice. The figure 4.23 above then shows the amount of water requirement in the basin that has been continually decreased in the past 10 years because the irrigated rice are not expanded, it has been converted into other crop activities instead.

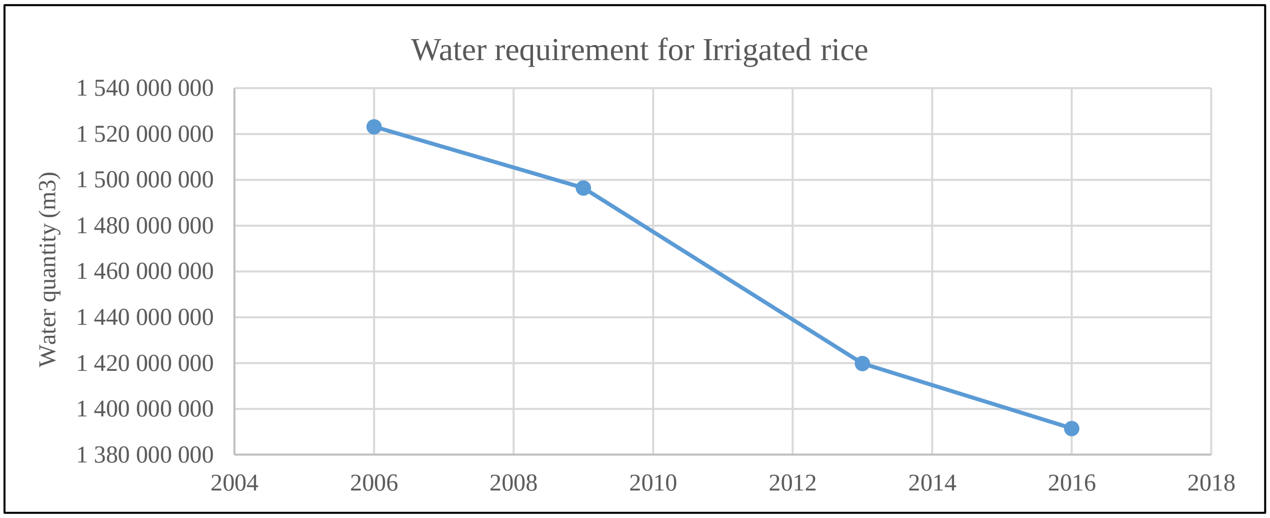

Figure 4.24 : Water requirement for irrigated rice in 2006-2016

4.3.4 Water requirement of fish and shrimp farming

Fish and shrimp farming is another agricultural activities that irrigated water in the dry season. For water requirement of fish and shrimp, the farmers will raise around 3 cycles in one crop throughout the year. Each cycle, they will harvest the productivity while draining out the water in the pond and add more water in the pond. As a result, draining in and out of water into the pond consumes a lot of water resources.

Assessment of water requirement of fish and shrimp farming is slightly different from irrigated rice as the period of crop is different. For rice, the Kc of rice is around 13 week long since its sowing date till its harvesting date while fish and shrimp is a longer term activities, generally, fish and shrimp use around 9-12 months before it is ready for harvesting. Thus, raising fish and shrimp normally takes a year. The Kc for fish and shrimp is then used as a monthly and using the same Kc (1.0) throughout the year.

Table 4.24: the surface area of fish and shrimp farming in the basin in 2002-2006

Province	Year (ha)				
	2002	2006	2009	2013	2016
Prachinburi	5,625	14,954	15,467	17,423	17,724
Chacheongsao	26,791	42,706	50,406	55,254	57,575
Sakaew	-	143	160	158	144
Nakhon Nayok	4,237	9,818	10,281	10,492	12,428
Total	**36,653**	**67,620**	**76,314**	**83,326**	**87,871**

Table 4.25: Calculation of crop evapotranspiration or crop water requirement of 4 provinces in the basin.

Month	Kc	Reference evapotranspiration (Eto) in each station				Crop water need (mm/month)			
		Prachinburi Station	Chacheongsao Station	Sakaew Station	Nakhon Nayok Station	Prachinburi Province	Chacheongsao Province	Sakaew Province	Nakhon Nayok Province
November	1	4.1	3.47	3.92	4.1	123	104	118	123
December	1	4.07	3.51	3.78	4.07	126	109	117	126
January	1	3.87	3.85	3.96	3.87	120	119	123	120
February	1	4.04	3.83	4.46	4.04	113	107	125	113
March	1	4.3	4.19	4.67	4.3	133	130	145	133
April	1	4.62	4.31	4.66	4.62	139	129	140	139
Total						**754**	**699**	**767**	**754**

To calculate the water requirement of fish and shrimp farming in the Table 4.26, a monthly Kc value needs to be multiplied with reference evapotranspiration in each 4 provincial station. After that, use crop water needs (Etc) of 4 provinces only in the dry season and multiply it with the surface area of fish and shrimp farming (The table 4.25)

Table 4.26: Water requirement for fish and shrimp farming in Bang Pakong basin in 2006-2016 in the dry season

Agriculture activity	Year			
	2006	2009	2013	2016
Surface area of fish and shrimp farming	67,620	76,314	83,326	87,871
Water for fish and shrimp farming	486,295,746	547,587,721	597,783,208	630,772,899

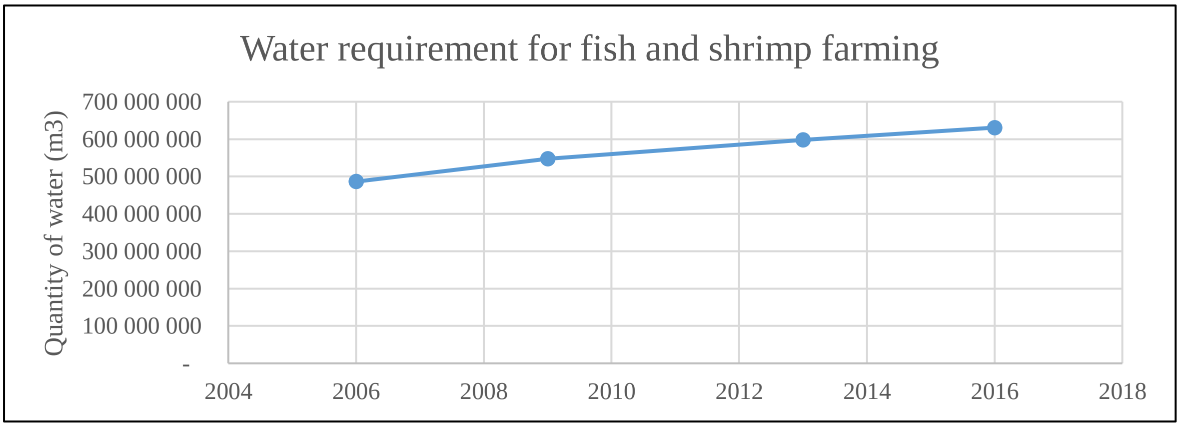

Figure 4.25: water requirement for fish and shrimp farming in 2006-2016

The Table 4.26 shows both surface area of fish and shrimp farming in the dry season (November-April) during the last 10 years (2006-2016). Due to an annual increase of surface area of fish and shrimp farming, the water requirement from 2006-2016 has also increased year by year.

As a result, the water requirement of fish and shrimp farming based on the calculation of Penman-Monteith equation is approximately 7,180 m3/hectare. According to the table 4.26 and the figure 4.25, the water requirement for fish and shrimp has been increased from 2006 until 2016 as farmers invest more in fish and shrimp production because it returns quite a high income for them.

4.4 Data collection on public organizations

Based on the data collection about land use changes and water needs in 3 sectors in Bang Pakong river basin, there are several relevant public organizations in the study areas whom in charge of those data.

Table 2.27 : Key informant from relevant public organization

Relevant Public Organizations	
Agricultural Organization	Water/ Water Management organization
1. Agricultural Extension Office (OAE)	1. Bang Phluang Irrigation Office
2. Industries Office	2. Fisheries Office
3. 6Th Regional Office of Agricultural Economics	3. Provincial Waterworks Authority (PWA)
4. Fisheries Office	4. Regional Irrigation Office 9th

- **Prachinburi Agricultural Extension Office (OAE)**

Agricultural Extension Office basically takes a response of the data on agriculture which are live stocks and agricultural crops. The Office supports in terms of agricultural knowledge and materials for farmers. Specifically, the Office collects statistics of agricultural crop cultivation of farmers in the province.

Therefore, crop cultivation data from OAE includes only economic crops and the number of crops are summarized only farmers' registered.

- **Bang Phluang Irrigation Office**

Bang Phluang Irrigation Office in Prachinburi province supports the water resource for water users in Prachinburi province mainly for the farm sectors. The Irrigation Scheme in charges of the area only within irrigation zone. There are 4 priorities for water users in Bang Phlung Irrigation Scheme which are Drinking water, maintaining the ecosystem (pushing salinity water), farm sectors and industries. The main water source of the Irrigation Scheme is from Prachinburi river.

- **Prachinburi Industries Office**

Prachinburi Industries Office mainly supports and in charges of industrial registering in the province, consult in terms of industrial production which is under an actual Laws of environment and safety. For water resource, their Office does not have any statistics and does not measure the amount of water pumped in each industry. However, they only response on monitoring some industries who release waste water. The Office then has to monitor their waste water treatment ponds and the water treatment system to make sure that the quality of released waste water is acceptable and won't affect to environment.

Based on the interview with a staff from this Office, they seem to seriously monitor and check the water quality as they have their own laboratory and concern a lot about released waste water from the industries in the province. Moreover, they plan to encourage many industries to use more clean technology and clean resources to help saving more water resources.

However, their cooperation with other organizations or offices are very limited. Also, the Office does not concern much about the amount of water pumped each day by each industries.

- **Prachinburi Fisheries Office**

Prachinburi Fisheries Office mainly in charges of aquaculture, knowledgeable and material supports for fisherman. Moreover, similar to OAE, Fisheries Office also needs to collect the area of aquaculture farm from farmers' registered especially with fish and shrimp farming.

However, in terms of water needs for aquaculture sector, their Office also does not have such data. On the other hand, they only collect the areas of aquaculture crops in the province.

Also, similarly to OAE, the numbers of aquaculture areas in the province does not included for the whole province. Their statistics are mentioned only farmers' registered.

- **Prachinburi Provincial Waterworks Authority (PWA)**

PWA basically conduct surveys, provide sources of the water and procure raw water for production. PWA mainly focuses on drinking water sector. The main water source is from Prachinburi river.

Their statistics on drinking water sector is the most obvious figure because on each day, they have a specific amount of water they produce and deliver to each household. Also, each household needs to install a metre which can be accurately measured the number of water use per day.

- **6Th Regional Office of Agricultural Economics**

6Th Regional Office of Agricultural Economics takes a response in terms of data on agricultural of 4 provinces in the Eastern of Thailand (Chonburi, Rayong, Chanthaburi and Trat provinces) and another 5 provinces in the middle central of Thailand (Chachoeungsao, Samut Prakarn, Nakhon Nayok, Prachinburi and Sra keaw provinces.)

Their mainly duties are to distribute the agricultural statistics of those province to public, work on Economic Development Plan and strategies plan. Also support, especially on economics crops. The Office cooperates with each Provincial Agricultural Office to monthly discuss with all agricultural statistics on each province and make sure that the numbers of crop cultivations are identical then the figures on agriculture will be finalized and distribute to public.

However, their statistics on provincial crop cultivation are only for economics crop (12 types of crop). And the statistics are only from farmers' registered.

- **Royal Irrigation Office**

Regional Irrigation Office 9 collects the data on water use for all water sectors (drinking water, industries and agriculture). Their responsibilities are cover 4 provinces in the Eastern of Thailand (Chonburi, Rayong, Chanthaburi and Trat provinces) and another 4 provinces in the middle central of Thailand (Chachoeungsao, Nakhon Nayok, Prachinburi and Sra keaw provinces.)

The mainly duties are to develop water resources and to increase irrigated area according to their potential and natural balances, to manage equity and sustainability of water allocation, to prevent and mitigate water hazards as appropriate missions and to encourage a public participation on water resources management and development.

The Office collects the data for all the water sectors in Bang Pakong, Prachinburi and Tonlesap river basins. Based on the interview with them, their water management plan is quite effective. Moreover, their data on water uses are quite practical and useful. For example, they apply spatial analysis on GIS and satellite imagery to identify crop cultivation areas then calculated the water needs for each sector. Therefore, the data will include all crops cultivation in the whole province, not only from farmer's registered.

Table 2.28 : Roles and Issues of relevant organizations for each water sector in the basin.

Water sector	Roles and Issues of relevant organizations for each water sector	
	Non-irrigation scheme area	**Irrigation Scheme area**
1. Domestic use/Water supply/Drinking water	➢ Each Provincial Waterworks Authority (PWA) directly takes a responsibility in terms of water supply. They measure their water pumping daily as they need to pump raw water and produce it then allocate to each household. The measurement of water pumping is from the metre equipment and the metre at each household.	➢ PWA needs to report the data on water pumping for RID.
2. Industries	➢ Industrial Office takes the water quality more than the water quantity into account. ➢ Industrial Office does not check the water pumping for each industry, but they only concern and check in terms of the waste water treatment system. ➢ Industrial Office does not have the data on water pumping in each industry/factory.	➢ RID (whom in charge in the basin scale) will collect the data of water pumping for industries by getting data directly from the report and interview with the Big Water Company who pumped the water and sell it to each industry.
3. Agriculture	-	➢ RID and Bang Phluang Irrigation Office will assess the water requirement for crops and aquaculture by calculating with the crop evapotranspiration as they need to manage the water for each sector effectively. ➢ Other irrigated organization: Agricultural Extension Offices and Fisheries Office do not measure or assess the water requirement for crops, they only concerned in terms of crop and aquaculture' registering and they collect the data on the surface area not with the water assessment.

4.4.1 Issues on data collection of land use

One of the main issues in the study area in terms of land use is an accuracy of the data on agricultural statistics. Based on the interviews, mostly Provincial Agricultural Offices collect the statistics of crop cultivation only from farmer's registered. Specifically, each district has to report their crop cultivation. For example, the number of rai of rice paddy in their district. The problem is that district officers who in charge in the area are not enough. In some cases, one officer needs to work at least 2-3 districts in the same time. Therefore, the officers cannot check all the crops cultivation in the areas very thoroughly. In addition, it is seemingly that they do not apply spatial tools such as maps or GIS system to work with them but only rely on the data from farmers' side which sometimes are not accurate and reliable because not every farmer will inform their exactly number of crops. Some crops which are not announced as an economic crops, farmers won't register to the Office. On the other hand, if their crops are included in one of the economic crop, that means when the farmers register to OAE, they will get a support from government because the government will guarantee the price for those economic crops. Nowadays, OAE mentioned that they have only 50% of farmers who come register their crops.

As a consequence, if comparing the data of agriculture land from Land Development Department (LDD) which is from Satellite Imagery with the data of agriculture land from OAE which collected from farmer's registered, the number of crops cultivation are huge different. As shown in the table 4.10 above, compared perennial crops in Prachinburi province from Land Development Department and Office of Agricultural Extension.

Moreover, the agricultural statistics are only concerned about economic crops (Napee rice and Naprang rice, maize, cassava, pineapple, sugarcane, durian, mangoesteen, rambutan, longon, lychee, oil palm and rubber tree). It is not included all types of crops in the province.

This also similarly happened with the data on aquaculture land. Regarding to the interview with Provincial Fisheries Office, the numbers of aquaculture area in the province also does not included the whole province but the statistics are only mentioned from farmers' registered.

4.4.2 Issues on data collection of water pumping

Another issue on water resources' data in the basin is measuring water pumping. Most of the Offices that have been interviewed, they hardly collect or measure about data on water pumping or water needs for each sector especially on industrial sector which is the most difficult sector to know the water pumped from each industry. Basically, there are big water companies who pumped a large amount of water from the river or reservoirs and sell this water to the industrial estate. In the study area, there are two main big water companies which are East Water Company and 304 Company.

East Water was introduced by PWA, supposed to support in Eastern Seaboard Project. PWA needs to support the water resources to both water supply and industries. However, the Prime Minister of Thailand at that time concerned that PWA should only focus on water supply instead of allocate the water for both sectors because industrial sectors need raw water. Thus, East Water was founded since then due to supporting the raw water for only industrial sector in 1992. Nowadays, East Water is registered itself as a Company Limited and support the raw water for most of the industrial estate in the Eastern of Thailand.

Apart from East Water Company, in Prachinburi province, another big water company is 304 Company and they affiliate others small companies such as Namsai 304 in order to pump the water in the river and send back to them.

Those big water companies pumped a large amount of water from Bang Pakong, Prachinburi rivers and also from some reservoirs. However, the rivers that they pumped the water is not inside an irrigation area. In this case, RID cannot in charges or monitors their water pumping' behavior because it is out of RID's control. Especially in Prachinburi province, 304 company pump the water from Prachinburi river which is outside waterways irrigation. Waterways irrigation is announced as a reservoir or canal but for the river which is naturally, it is not included in waterways irrigation because regarding to the Laws, river and water resources are not belongs to anyone. In that case, it does not have any policy to control pumping water directly from the river because everyone can access the water resource without asking any permission from RID.

The problem is that when everybody can access to the water resource in the river without any policy to control, a big water company can pump the water as much as they want and RID cannot control them. However, once RID interviewed with those big water companies to collect their water pumping, they hardly got any useful information, no specific on number of pumping water but only overall figure and no one can assure whether those number are reliable. Theoretically, Industrial Office has to collect the water consumption of each industries that registered into industrial system before Department of Industries will collect all of the water use and calculate the water uses for industries in the future.

Another problem is that when the water is pumped from the river, especially in the upstream area, the water budget will be a lot decreased and that will affect with the water users in the downstream area. This is why the Water Act 2017 is stimulating in order to encourage every water sector, especially industries to take a responsibility about pumping water from the rivers.

Apart from industrial sector, the water need for agriculture and aquaculture are also one of the problems because the relevant Offices such as OAE and Fisheries Office do not have the data on water needs and less people is interested to take that into account, only RID calculate the water needs for every sector.

4.5 Land use and water use scenarios

The scenario is projected under a business as usual scenario to estimate the trend of land and water use in Bang Pakong river basin in the future in order to plan for water management in the study area.

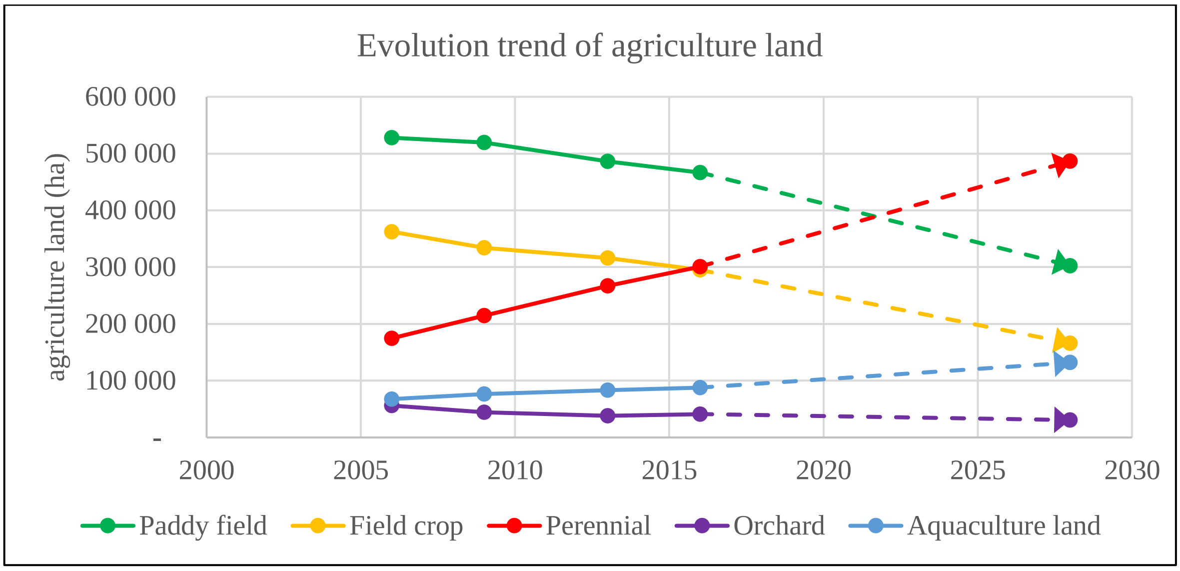

Figure 4.26 : Agriculture crop area evolution in 2028

The figure 4.26 shows the agriculture land projection with the base line since in the year 2002 – 2016 and project the evolution of agriculture activities in 2028 as agriculture land is the most changed land in the study area and it is going to effect a lot for water resources in the basin. The evolution in 2028 shows that perennial crops and aquaculture land tend to increase in the future while other types of agriculture tend to decrease.

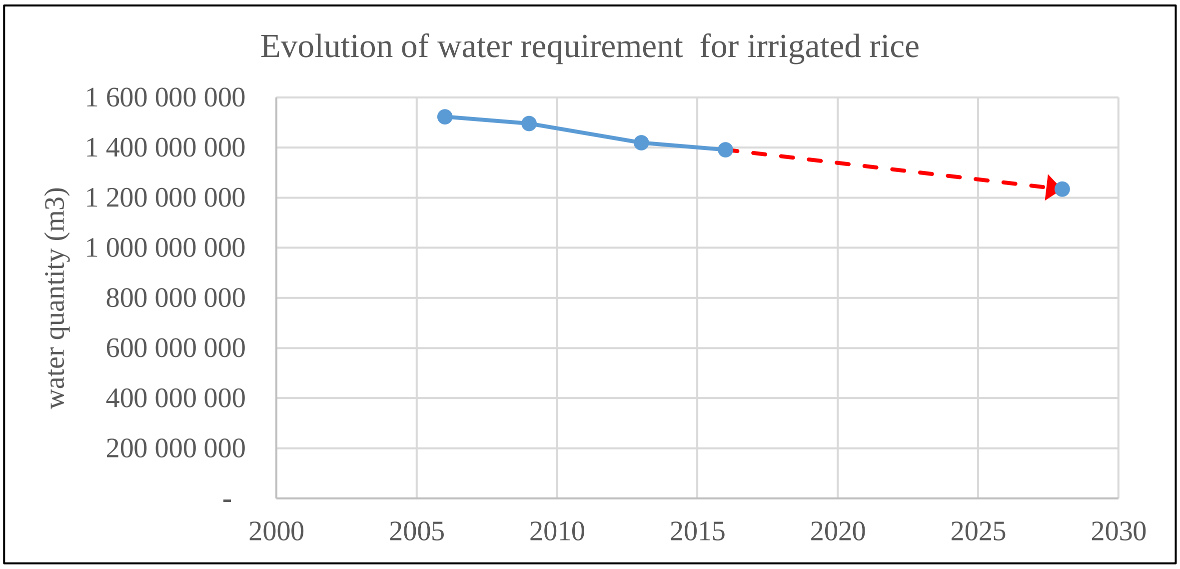

Figure 4.27 : Water requirement for irrigated rice evolution.

The Figure 4.27 shows the evolution of irrigated rice in the next 10 years. Between 2006-2016, the trend of irrigated rice has been decreasing. Irrigated rice is one of the major crop activity that irrigates water in the basin and it is clearly that rice is the most used of all crops in the basin.

According to the trend of water requirement of irrigated rice in the past 10 years and project the trend of water requirement in the next 10 years, this study can assume that irrigated rice might not be the crop that affects with water resources much in the future. On the other hand, as it is can be seen in the Figure 4.27 that the evolution of water requirement is decreasing, in the future, irrigated rice or even non-irrigated rice are less expanded in the basin while others agricultural activities which will return more income to the farmers are going to be more expanded. The farmers are going to change their crops activities based on the market price. Therefore, water requirement for rice will not affect with the water resources much in the future based on the evolution trend in this study.

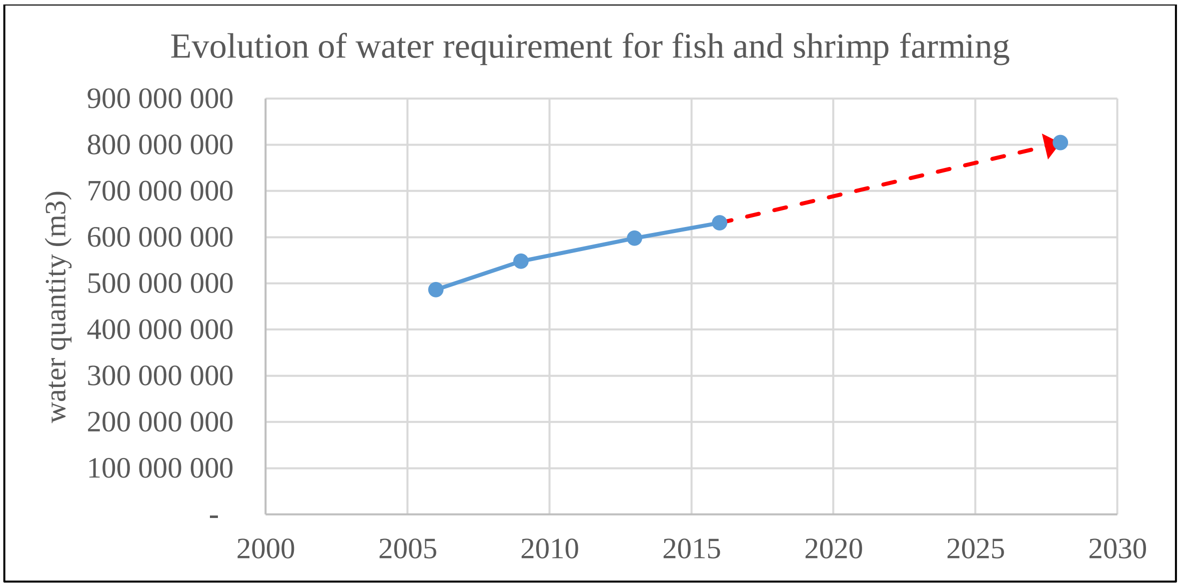

Figure 4.28 : Water requirement for Fish and Shrimp evolution

The evolution of water use for Fish and Shrimp evolution in 2028 is shown in the Figure 4.28, Fish and Shrimp farming is the most used water for agricultural activities. The farmers used to pump out all the water in the pond. The farmers pump the water directly from the river or from irrigation canals by their pumping machines and fill in their pond. During the crop yield, the water is evaporated. Thus, the farmers need to fill more water in the pond approximately three times a year. As a result, this agricultural activity is the most consumed water in the basin, especially in Nakhon Nayok, Prachinburi and Chacheongsao province where there are many fish and shrimp productions.

Based on the projection of business as usual scenario of fish and shrimp farming, the water requirement for fish and shrimp which is assessed in the dry season (November-April) is continually increased during the last 10 years, between 2006-2016 and the projection is clearly that the water requirement is going to increase in the future as well.

This scenario trend of water requirement will definitely effect with the water resources in the basin in the future because fish and shrimp is normally irrigated water from irrigation area or the farmers pump the water directly from the river as most of the fish pond located nearby the river. In terms of water management for fish and shrimp, The Royal Irrigation Department in Chonburi Province has managed the water resources by encouraging the farmers to irrigate the water in their pond only one time. The farmers can only fill the lost surface of water based on an evaporated rate of the water in the pond otherwise it will consume too much of water especially in the dry season as it is not only fish and shrimp that need the water in the dry season but other crop activities also need to irrigate the water.

Moreover, for fish and shrimp farming, the farmers also need to stock their own water just in case that there is not enough water in the river (in the dry season or when the time that the saline water is going up).

Meanwhile, Royal Irrigation Office has a near future plan to expand more irrigation scheme in many parts of the basin, especially for the new reservoir projects which are not yet have its own irrigation scheme such as Huay Samong Dam and Phra Phrong reservoir in the upper part of the basin.

Apart from the evolution trend of agriculture crops in the next 10 years, increase of industries is also one of the main factors impacted with water use in the basin. Due to the confirmed up-coming projects of Eastern Economic Corridor (EEC) in Eastern region of Thailand which will be one driver of land use change in Bang Pakong river basin. Eastern Economic Corridor (EEC) is planned to develop the eastern economic to become a “World-Class Economic Zone” , support an industrial investment in the future and also several economic activities such as transportation of ASEAN and distribution center (BOI,2017).

Those incoming projects will focus on industrialization, it is obviously that the water needs for industries are going to impact the water resources in the basin as nowadays, Rayong and Chonburi provinces are the most developed provinces in terms of industrial sector and also use the most amount of water resources.

The main concept of EEC is 3+2 based on an interview with RID. Three means Chonburi, Rayong and chacheongsao provinces while two means Prachinburi and Samutprakan provinces. Firstly (in 2016-2022), the development is planned to focus in those 3 provinces. After that another 2 provinces will be developed next.

For Chacheongsao province, the purpose in EEC project is not about industrial development instead, it will be focused on residential purpose. In this case, the evolution of water use for domestic will be increased in the future. Moreover, Chacheongsao province has a problem on a inequity use of water as some parts of the province depend on PWA while the upper part of the province which is urbanized needs to pump the water from the canals and often faces with lack of water to use in the dry season. As a result, RID plan to connect the intakes to pump the water from the reservoir from the lower part of the province and provide it to the upper part.

For Prachinburi in EEC context won’t be effected much in terms of expansion the industrial zone but land use will be changed from an urbanization and decrease of agriculture land in the future.

CHAPTER 5
CONCLUSION

5.1 Conclusion

The study based on classified imagery, assessment of crop water needs and the projection of the evolution trends under business as usual scenario on land and water use showed that agriculture and forest land are the most proportion of land use category in Bang Pakong river basin. For agricultural change, perennial crops and aquaculture land are the agricultural activities that increased the most in this case while paddy field, field crop and orchard decreased in the past 10 years. Moreover, based on the business as usual scenario in the next 10 years, fish and shrimp farming are going to increase the water needs and will effect with water resources in the basin.

The analysis on water use from the relevant organizations and from the previous study demonstrated that in Bang Pakong river basin, water resource has been used for different sectors: agriculture sector, water supply, domestic purpose, industries and ecological maintenance and evaporation. Agricultural sector is the most used water resource in the study area following with ecological and evaporation, water supply, domestic use and industries. Our own basis on crop water needs using Potential Evapotranspiration (ETp) analysis applied with Penman- Monteith to assess water requirement for crops. In the dry period between November to April, only irrigated rice and fish and shrimp farming irrigate water while other agricultural activities such as perennial crops, field crops, orchard, and even for the major rice crop (Napee-rice) will depend mainly on rainfall. The result showed that dry season rice needed to irrigate the water averagely 5,500 m3/hectare. Therefore, the irrigated rice in the past 10 years (2006-2016) required water averagely around 1,500,000,000 m3 in the dry season.

Another agricultural activity that irrigated water in the dry season is fish and shrimp farming. The result showed that in the dry season, fish and shrimp farming needed to irrigated the water averagely 7,180 m3/hectare. Therefore, fish and shrimp farming in the past 10 years (2006-2016) required water averagely around 560,560,989 m3.

Many public organizations in the basin who works relevant to land and water resources are still lack of coordination among their offices. According to the interviews with the officers from the relevant offices, each office works on their own, and does not concern much about another relevant offices which is basically should discuss and share the data among them. From my point of view, the data on land and water use in the basin are completed but the data is floating into the air. Most of them lack of data management.

The business as usual scenario by 2028 was prepared for projecting the evolution of land and water use in the study area. Based on the major agricultural activities in the study area: Paddy field, field crop, aquaculture, orchard, perennial. The scenario demonstrated that perennial crops and aquaculture tend to increase the land in 2025s while paddy field, field crop and orchard tend to decrease its land. In terms of water requirement scenario, irrigated rice or rice in the dry season rice tend to decrease the water use in the future while fish and shrimp farming tend to increase the use of water in the next 10 years.

As the relevant organizations are getting in charge and dealing with the issues on water resources in the basin especially on water management and water allocation for each water sector to support the water resources equally to everyone. However, in the basin itself has a geographically issue on saline water intrusion every year. If they do not have enough fresh water to flush out the saline water that normally goes up in the dry season, it will have a lot of damages on various agricultural crops, especially rice paddy which irrigated water from the river. Moreover, saline water can impact on the water supply in urban land, these will take so much of risks. Thus, the water resources for flushing out those saline water is the most essential part in the basin. Recently, construction of dam and reservoir projects in the upper part of the basin has been prepared to support those ecological maintenance and flushing of saline water and seem to be helpful for solving those issues.

However, it still needs more water resources in the future to support each water sectors in the basin. RID and relevant organizations plan to propose more reservoirs to stock more water to use, especially in the dry season for some agricultural activities that need to irrigated water along with the issue of land use change due to population increase and urbanization that is going to take place for an up-coming project of Eastern Economic Corridor in Eastern region of Thailand. Those drivers lead to more land use change in Bang Pakong river basin and will impact with water resources in the future.

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APPENDIX

Table: Area of perennial crops in the study area in 2002-2016

		Area of perennial crops (ha)				
		2002	2006	2009	2016	2016
	Total	**20,943**	**82,341**	**97,806**	**116,774**	**131,223**
Changwat Chachoengsao	Amphoe Ban Phoe	-	101	101	46	43
	Amphoe Bang Khla	2	26	61	1,254	1,255
	Amphoe Bang Nam Pieo	43	9	9	139	178
	Amphoe Bang Pakong	-	20	42	68	71
	Amphoe Khong Khuain	258	75	75	727	707
	Amphoe Muang Chachoengsao	2,014	510	592	1,557	1,500
	Amphoe Phanom Sarakham	796	6,550	8,781	8,445	9,163
	Amphoe Plaeng Yao	5,831	7,695	11,299	12,158	12,555
	Amphoe Ratchasan	-	-	-	118	75
	Amphoe Sanam Chaikhet	10,301	38,340	45,715	51,653	53,267
	Amphoe Tha Takiap	1,698	29,015	31,131	40,609	52,409
Changwat Nakhon Nayok	**Total**	**2,424**	**5,113**	**5,322**	**5,492**	**6,348**
	Amphoe Banna	1,504	1,108	1,180	1,081	1,685
	Amphoe Muang Nakhon Nayok	276	425	364	509	585
	Amphoe Ongkhalak	66	2,916	3,288	3,100	3,212
	Amphoe Pakphli	578	664	489	802	866
Changwat Prachinburi	**Total**	**26,418**	**37,652**	**61,236**	**73,883**	**71,833**
	Amphoe Ban Srang	1	7	31	36	23
	Amphoe Kabinburi	7,590	20,768	33,610	41,357	41,356
	Amphoe Muang Prachinburi	6,591	1,066	3,150	4,071	4,150
	Amphoe Nadi	2,062	6,302	11,392	12,815	11,601
	Amphoe Prachantakham	2,745	1,427	2,091	3,821	3,934
	Amphoe Sri Mahosoit	264	861	1,079	1,443	1,300
	Amphoe Srimahapho	7,165	7,221	9,881	10,340	9,469
Changwat Srakaeo	**Total**	**36,649**	**71,792**	**59,578**	**81,132**	**113,408**
	Amphoe Aranyaprathet	1,703	3,524	4,264	4,338	5,974
	Amphoe Khao Chakan	1,402	5,825	5,820	8,180	8,800
	Amphoe Khlong Hat	2,666	4,011	4,074	4,590	5,877
	Amphoe Khoksung	770	857	1,193	1,816	2,547
	Amphoe Muang Srakaeo	14,635	29,379	16,595	24,363	41,009
	Amphoe Taphaya	1,575	1,944	2,190	2,762	2,887
	Amphoe Wang Nam Yen	1,418	4,422	4,472	5,646	5,538
	Amphoe Wang Sombun	2,602	5,508	5,462	8,089	9,830
	Amphoe Wattana Nakhon	9,877	16,323	15,508	21,347	30,947
	Total	**86,435**	**196,897**	**223,942**	**277,281**	**322,812**

Table: Area of aquaculture land in the study area in 2002-2016

		Area of aquaculture land (ha)				
		2002	2006	2009	2013	2016
Changwat Chachoengsao	**Total**	**26,791**	**42,706**	**50,406**	**55,254**	**57,575**
	Amphoe Ban Phoe	7,324	9,153	9,972	10,612	10,519
	Amphoe Bang Khla	1,652	10,073	9,885	10,234	10,536
	Amphoe Bang Nam Pieo	790	6,617	7,661	3,560	3,871
	Amphoe Bang Pakong	13,388	4,667	8,053	12,410	12,345
	Amphoe Khong Khuain	371	2,622	2,875	2,731	2,738
	Amphoe Muang Chachoengsao	2,690	2,802	5,331	7,900	8,146
	Amphoe Phanom Sarakham	102	2,718	1,615	1,647	3,318
	Amphoe Plaeng Yao	165	1,777	2,119	2,426	2,305
	Amphoe Ratchasan	309	2,205	2,811	3,662	3,744
	Amphoe Sanam Chaikhet	-	15	33	32	28
	Amphoe Tha Takiap	-	58	51	39	24
Changwat Nakhon Nayok	**Total**	**4,241**	**9,931**	**10,394**	**10,605**	**13,944**
	Amphoe Banna	145	1,144	1,328	1,273	1,544
	Amphoe Muang Nakhon Nayok	1,477	3,040	3,175	3,224	5,288
	Amphoe Ongkhalak	2,382	5,106	5,266	5,398	6,139
	Amphoe Pakphli	237	641	626	709	973
Changwat Prachinburi	**Total**	**5,625**	**14,954**	**15,475**	**17,423**	**17,724**
	Amphoe Ban Srang	4,929	12,239	12,486	13,726	14,163
	Amphoe Kabinburi	-	149	111	53	54
	Amphoe Muang Prachinburi	414	1,181	1,381	1,857	1,846
	Amphoe Nadi	-	14	26	24	20
	Amphoe Prachantakham	15	305	280	304	280
	Amphoe Sri Mahosoit	105	650	680	855	829
	Amphoe Srimahapho	162	415	511	604	531
Changwat Srakaeo	**Total**	**-**	**143**	**160**	**158**	**144**
	Amphoe Aranyaprathet	-	-	-	8	0
	Amphoe Khao Chakan	-	6	6	6	6
	Amphoe Khlong Hat	-	18	18	18	20
	Amphoe Khoksung	-	-	3	3	8
	Amphoe Muang Srakaeo	-	17	24	24	24
	Amphoe Taphaya	-	-	-	-	-
	Amphoe Wang Nam Yen	-	3	3	-	-
	Amphoe Wang Sombun	-	5	12	5	5
	Amphoe Wattana Nakhon	-	94	94	94	80
	Total	**36,657**	**67,734**	**76,435**	**83,439**	**89,388**