Remote Sensing and GIS for Mapping and Monitoring Land Cover/Land Use Changes in the Phu Tan District of Ca Mau Province, Lower Mekong Delta

Hanh Hong TRAN, Viet Bach PHAM, and Cuong Sy NGO, Vietnam

Key words: Land cover/land use changes; Remote sensing; Phu Tan; Ca Mau

SUMMARY

The main aim of this paper is to assess the spatio-temporal changes of land cover/land use changes in the Phu Tan district of the Ca Mau province from 1989 to 2018. Multi-temporal remote sensing satellite images (Landsat) were collected, classified using supervised method, validated, used the post classification, and mapped for the land use/land cover change detection in decades. There are major land cover/land used classes include cultivated plants/trees, mangrove forest, aquaculture ponds, residents, and water bodies. The accuracies of the land cover/land use maps for three time intervals (1989, 2002, and 2018) were all more than 80%. Overall, the results show that over the last 30 years, the areas of cultivated plants/trees and water bodies were significantly decreased. In contrast, aquaculture ponds, mangrove forest, and residential areas were greatly increased. The policies, demographic, socioeconomic, and environmental changes were the main drivers of these changes in this case study.

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1. INTRODUCTION

Land cover/land use conversions include many drivers such as human activities, socio-economic, biophysical and environmental factors (Lambin and Geist, 2006). They may cause many significant impacts on worldwide biotic diversity, global and local climate, biogeochemical cycles, soil degradation, hydrology, food security, soil quality and human well-being, and the capacity of biological systems to support human demands (Lambin and Geist, 2003; Manandhar et al., 2009; Tian et al., 2014). In the context of global environmental changes, rapid population growth and rising demands for environmental sustainability nowadays, it is necessary to document land cover and land use changes, and to understand their drivers and consequences.

Coastal areas and plains are the areas of high population density and economic activities, leading to pressures and changes to these systems, including changes in land use. Ca Mau Province is a large coastal province located in the Mekong Delta with high poverty rates and diverse land uses. A significant body of research regarding land cover/land use change in coastal zones, estuarine areas and river deltas using remote sensing data already were studied (Gitau and Bailey, 2012; Byomkesh et al., 2012; Corner et al., 2014). A number of studies were detected and described the land cover/land use changes in several different districts of the Ca Mau Province or in the Mekong Delta (Binh et al., 2005; Lam-Dao et al., 2011; Tran et al., 2015; Karila et al., 2014). These studies concluded that mangrove forest and agriculture land decreased significantly, and changed to aquaculture and resident areas.

The major objective of this study is to document the spatio-temporal dynamics of land cover/land use change in the Phu Tan District of Ca Mau province over the last 30 years from 1989 to 2018 using the remote sensing and GIS methods. No study addressed these issues in details in the Phu Tan District. The Phu Tan District is a major case study because it is characterized by a mixture of diverse land cover/land use types which are specific in the Ca Mau province. They involve mangrove forest, cultivated plants/trees, aquaculture ponds, residents, and water bodies.

The Phu Tan District is a coastal and rural one of the Ca Mau Province. Ca Mau Province is a flat, low-lying region that is easily flooded due to both its low altitude from –1 to 3 m above sea level, and the high tidal fluctuations of the East Sea and the Gulf of Thailand. The Phu Tan District borders the Gulf of Thailand and is neighboring the Tran Van Thoi, Cai Nuoc, and Nam Can districts (Figure 1). Statistical yearbook in 2017 of the Ca Mau Statistic Office (Ca Mau Province Statistics Office, 2017) showed that the Phu Tan District has a total population of 109,642 people; the calculated population density is 246 persons/km^2. There are two seasons

including a rainy season and a dry season with an average annual temperature of 27.5 °C and an average annual rainfall of 2442 mm. There are one town and 8 communes in the district.

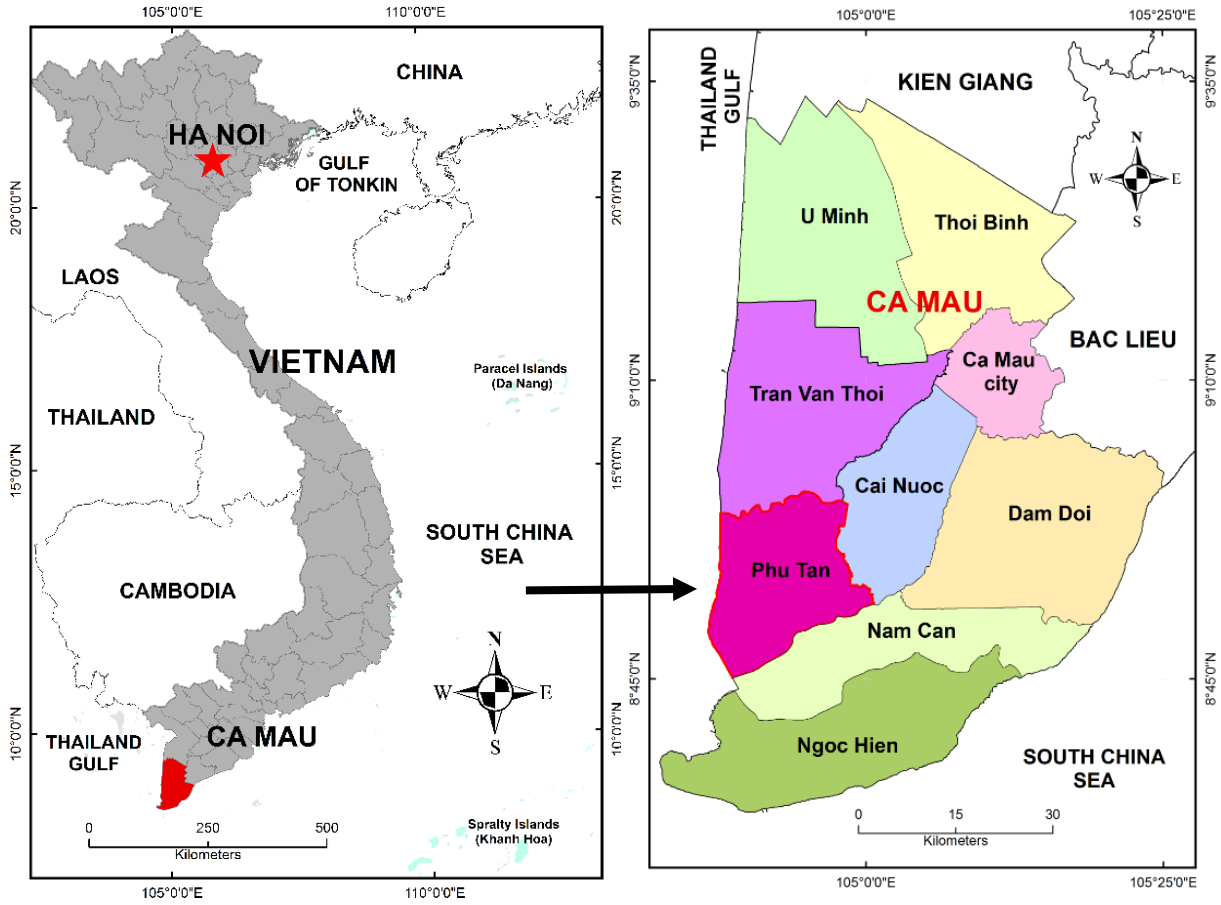

Figure 1. Location of the Phu Tan District in the Ca Mau Province

2. MATERIALS AND METHODS

2.1 Datasets

The ENVI 5.0 and ARCGIS 10.0 (ESRI) software packages were used for image processing and for spatial analysis in this research. The data used for this study include satellite images, ancillary data such as topographic maps and Google Earth© images (Table 1). The Landsat images were selected from the existing archives based on their limited cloud coverage, spatial and temporal extent. Digital GIS layers derived from topographic maps provided information on administrative boundaries, road, topography, water bodies, vegetation, and residential infrastructure.

Type	Data (Scale)	Date of Acquisition	Spatial Scale	Source
Remote sensing satellite images	Landsat TM 1989	24/02/1989	30 × 30 m	United States Geological Survey (USGS)
	Landsat ETM 2001 + 2002	16/01/2001 17/03/2002	30 × 30 m	
	Landsat 8 (Oli) 2018	12/03/2018	30 × 30 m	
Ancillary data	Topographic maps	1988, 2006	1:50,000	Department of Defense
		2010	1:5,000	
		2002	1:50,000	Ministry of Natural Resources and Environment
	Google Earth Imagery	-	-	Google Inc.

2.2 Processing

2.1.1 Pre-processing

The Landsat images used in this study from the freely available USGS archive. They were converted to reflectance, then applied dark subtraction of dark object sybtraction (DOS) for the atmospheric correction step. Topographic radiometric correction was omitted due to the low relief variation in Ca Mau Province (Vo et al., 2013). The satellite images were geometrically corrected to the Universal Transverse Mercator grid (UTM), zone 48, WGS84 ellipsoid and datum, using nearest neighbor resampling method. Each scene was georeferenced using 10 GCPs. All the images were geo-registered to the map with a root mean square (RMS) error of less than 0.5 pixels.

2.1.2 Classification

Topographic maps and Google Earth imagery were used for training sites of land cover/land use classification. For older time periods, existing topographic maps were used to select unambiguous training sites. Visual interpretation of recent images helped to select the most representative training sites for the older dates.

The number and typology of land cover/land use classes were defined based on the available land use statistics for the Ca Mau Province and Phu Tan District, and exploratory analysis of satellite data with unsupervised classification (generating 25 spectral clusters, later merged into 5 land cover/land use classes). There are five major land cover/land use categories of the Phu Tan District were identified inclusing magrove forest, cultivated plants/trees, aquaculture ponds, residents, and water bodies. The used typology was updated from FAO, 2015 to match with the characteristics of the case study.

The algorithm used for image processing follows the book of Campbell et al., 2011. Land cover/land use classification maps were established using the maximum likelihood

classification method. Training samples for the supervised classification in this case study were selected based on ancillary maps. A 3 × 3 majority filter was applied to reduce noise in the land cover/land use maps. Finally, independent training sites were used to assess the accuracy of each classification.

2.1.3 Change Detection Analysis

The area of each land cover class was calculated and the land cover/land use changes were analyzed. Based on the availability of cloud-free scene over the study area, the Phu Tan District was characterized the land cover/land use changes in 2 short-term periods (1989–2002, 2002–2018) and 1 long-term period (1989–2018).

Detection of land cover/land use changes changes was achieved by overlay and post-classification comparison of the land cover/land use maps of the different time periods at district scale. The resulting change maps were accompanied by the respective cross tabulation matrices showing the change pathways, in order to determine the quantity of the conversions.

3. RESULTS AND DISCUSSION

3.1 Land Cover/Land Use Classification and Accuracy Assessment

The overall accuracies of the classification of the land cover/land use in the Phu Tan District for the years 1989, 2002, and 2018 were 88, 84, and and 80%, respectively. The overall Kappa indices were 0.82, 0.80, and 0.74, respectively (Table 2). Although the producer and user accuracies of some classes were below 80%, the majority ranged from 80% to 100%, which is satisfactory considering the diverse land cover/land use categories in this case study. The classification errors were sometimes due to the spectral mixture between cultivated plants/trees and residents; cultivated plants/trees and mangrove forest; or aquaculture ponds and natural water bodies.

Land cover/land use classification maps of the Phu Tan District from the three time periods were analyzed and are shown in Figure 2. Mangrove forest which was located mainly in the southwestern part of the district, increased during the period of 30 years. In the past, mangrove forest dramatically reduced (Binh et al., 2005, Tran et al., 2015). The major factors that might have contributed to the loss of forest cover are the Vietnam War, the expansion of paddy rice cultivation, and shrimp farming (Lam-Dao et al., 2011, Lan, 2011). However, the local policies for re-planting the mangroves were applied in recent years (Arnaud-Haond et al., 2009).

Cultivated plants/trees, consisting almost entirely of paddy rice, are dominant in the northern, central and eastern parts of the district. It significantly decreases in the year 2018. Cultivated lands (paddy rice) were converted to aquaculture ponds, magrove forest, and the expansion of built-up areas due to the population growth and the socio-economic development (Binh et al., 2005).

In fact, there are only three land cover/land use classes in the classification of the year 1989. The reason is the image quality in this year of the case study is not good for the detailed classification. Residential category could not classsified during the year 1989 and 2002 due to the low quality images and the small area of residents at those times. Residents in these dates were mixed with the cultivated plants/trees, so that they became the mixture of houses and

garden. On these dates, the large scale of mangroves and cultivated lands could be easily classified.

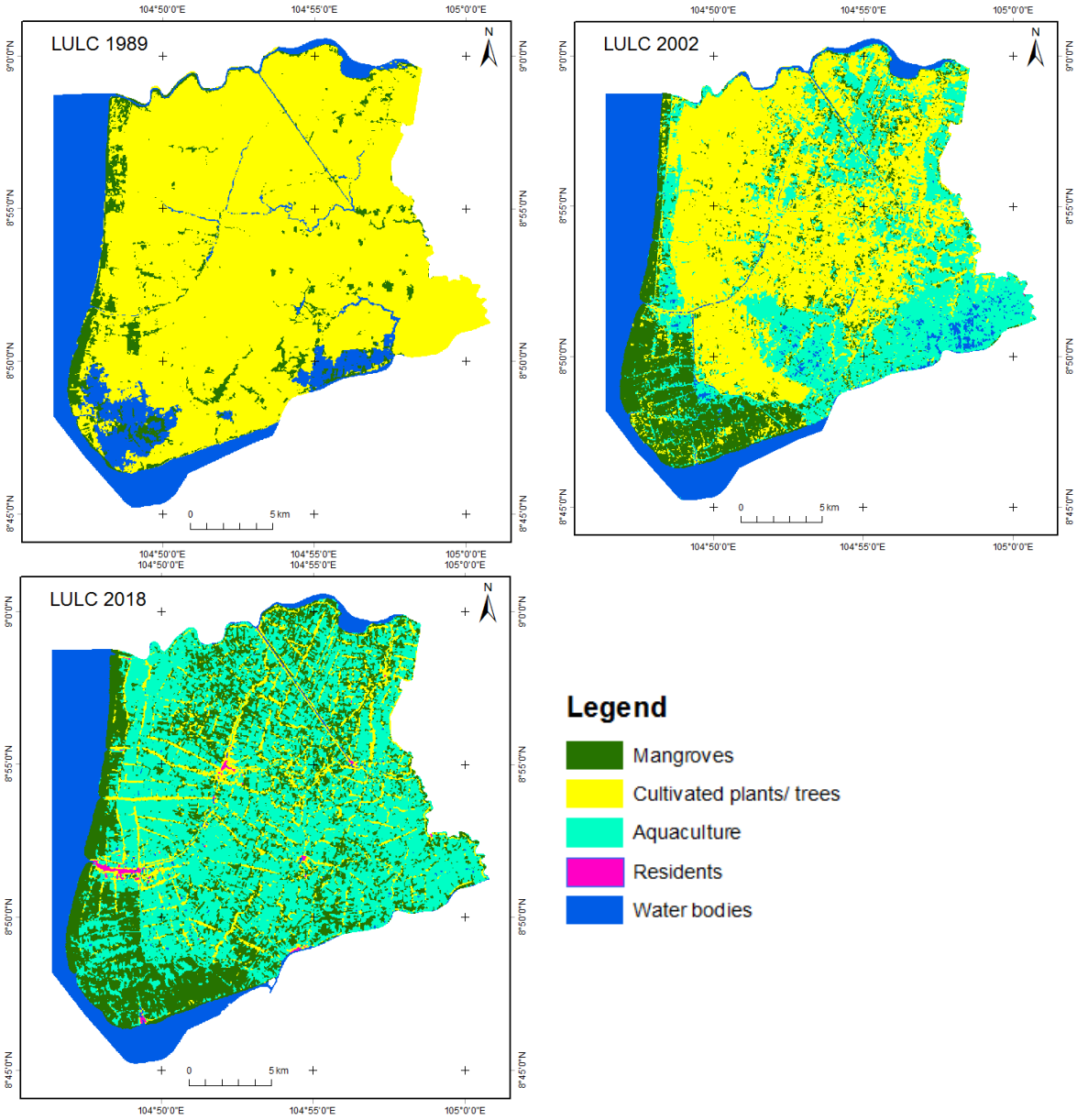

Figure 2. Land cover/land use classification maps of the Phu Tan District in year 1989, 2002 and 2018

Table 2. Accuracy assessment statistics of land cover/land use classification (in %) (*Abbreviation: Mangrove forest: Ma; Cultivated plants/trees: Cu; Aquaculture: Aq; Residents: Re; Water bodies: Wa*)

Land Cover/Land Use Categories		Ma	Cu	Aq	Re	Wa	Overall Accuracy	Overall Kappa
1989	Producer	78	100	59	79	92	**88**	**0.82**
	User	94	78	89	100	67		
2002	Producer	90	99	-	-	83	**84**	**0.80**
	User	98	78	-	-	100		
2018	Producer	93	48	87	76	83	**80**	**0.74**
	User	66	86	82	100	97		

3.2 Land Cover/Land Use Change Detection

Figure 3 shows the surface distribution in percent and the evolution of the proportion of each land cover/land use class in the different time periods. Aquaculture ponds occupied the least area in the 1980s but by the end of the study period, cultivated plants/trees and water bodies have become the smallest land cover types in the district.

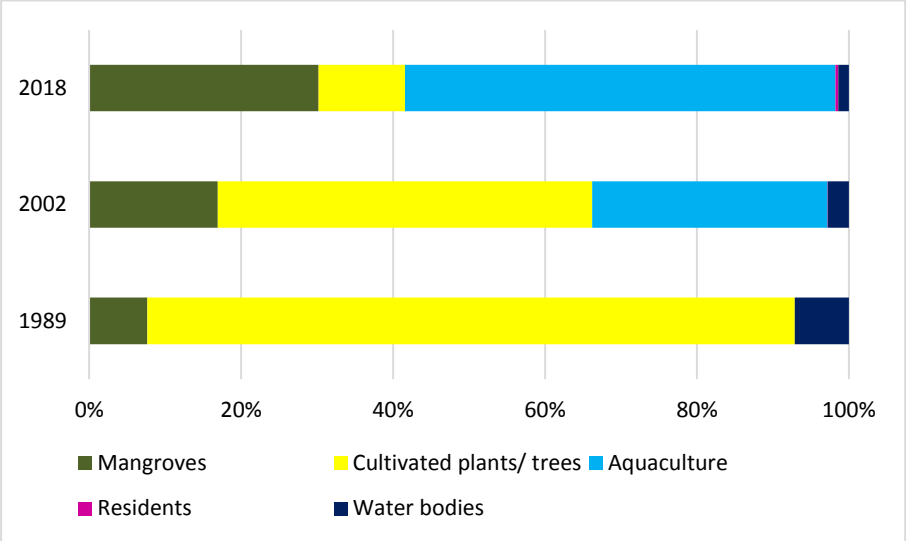

Figure 3. The distribution of land cover/land use types in percent in the Phu Tan District from 1989 to 2018

Figure 4 illustrates the spatial distribution of the different change types over the different time intervals. Cultivated lands changed during all the examined periods throughout the district, mostly due to expansion of aquaculture ponds. The conversion of mangrove forest and water bodies spreads in the eastern and western parts of the district in the 1989–2002 and 2002 -2018 periods.

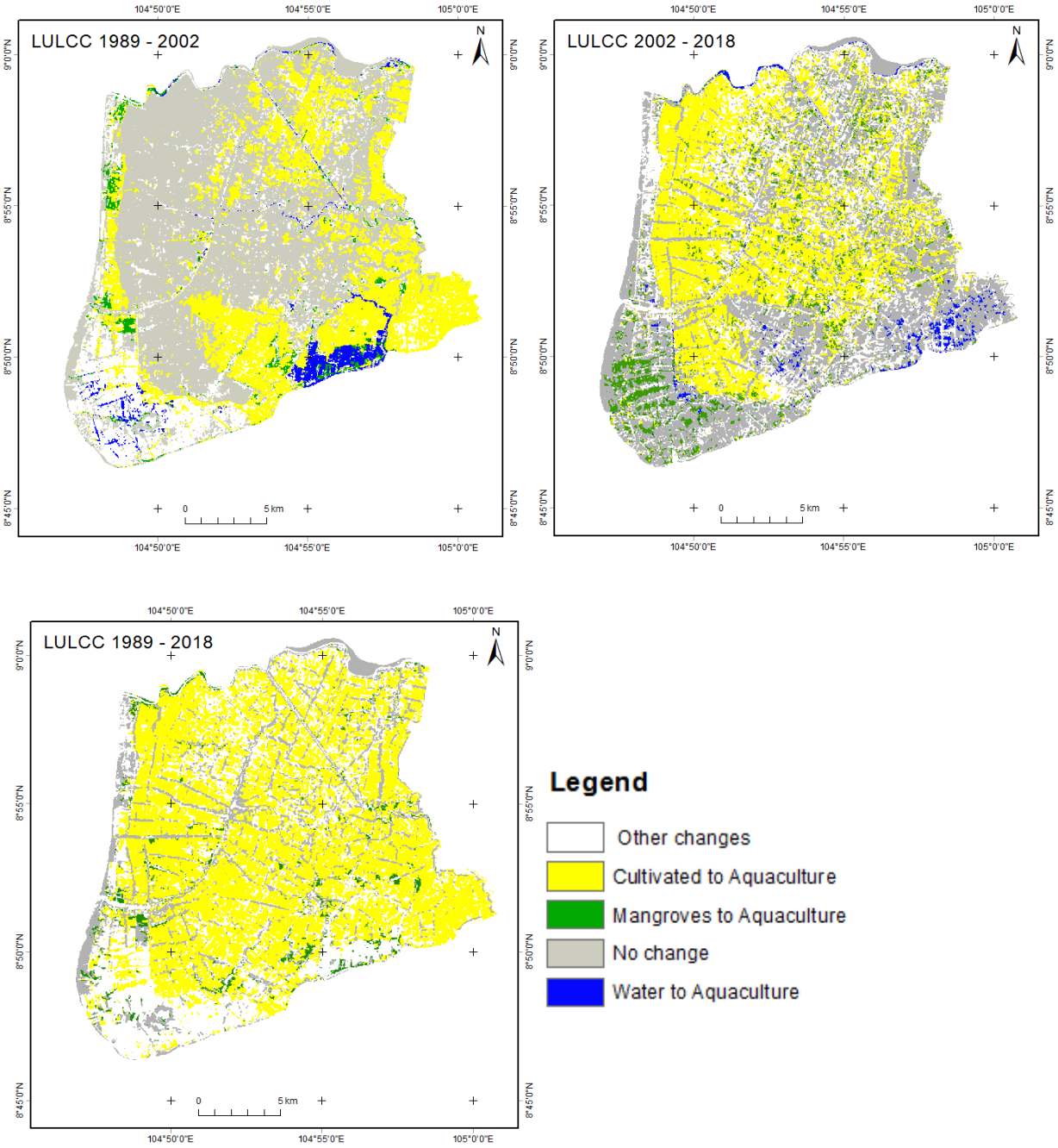

Figure 4. Spatial distribution of land cover/land use changes in the Phu Tan District from 1989 to 2018

The detailed dynamics in hectares of the land cover/land use changes in the Phu Tan District from 1989 to 2018 is shown in Table 3. The table presents all the results of the cross tabulation matrices of the land cover/land use change, showing the conversion from each class to another class. During the study period (1989–2018), 4,242 hectares cultivated plants/trees remained

stable, but 32,196 hectares of cultivated lands were lost to aquaculture ponds (22,150 hectares), mangrove forest (9,758 hectares), residents (116 hectares), and water (171 hectares). Mangrove forest and water body areas were the land cover/land use categories that changed to aquaculture ponds, with 1,010 and 1,120 hectares, respectively.

Table 3. Nature of the land cover/land use changes in the Phu Tan District from 1989 to 2018 (in hectares)

Period 1989–2002		**Ma**	**Cu**	**Aq**	**Re**	**Wa**	**Total (1989)**
1989	Mangrove forest (Ma)	1292	1036	851	0	62	3241
	Cultivated plants/trees (Cu)	4578	19921	11439	2	586	36525
	Water bodies (Wa)	1205	270	1021	0	549	3045
	Total (2002)	7075	21227	13311	2	1197	**42811**
Period 2002–2018		**Ma**	**Cu**	**Aq**	**Re**	**Wa**	**Total (2018)**
2002	Mangrove forest (Ma)	4170	434	2438	9	23	7073
	Cultivated plants/trees (Cu)	5187	3293	12554	87	102	21222
	Aquaculture (Aq)	3324	1068	8774	48	90	13304
	Residents (Re)	1	0	1	0	0	2
	Water bodies (Wa)	171	83	554	15	374	1197
	Total (2002)	12852	4877	24321	160	589	**42799**
Period 1989–2018		**Ma**	**Cu**	**Aq**	**Re**	**Wa**	**Total**
1989	Mangrove forest (Ma)	1647	439	1010	26	26	3148
	Cultivated plants/trees (Cu)	9758	4242	22150	116	171	36438
	Water bodies (Wa)	1326	190	1120	17	385	3039
	Total	12731	4872	24280	158	582	**42625**

The research result trends are similar with the results of past conversion analysis by Binh et al., 2005, Lam-Dao et al., 2011, and Tran et al., 2015 who analyzed a different district within the same province. They also showed that shrimp farms increased tenfold between 1999 and 2001. In addition to the Doi Moi policy, two additional policies/resolutions namely 09/NQ-CP in 2000 of the National Government and 1116/QĐ-CTUB in 2001 of the Ca Mau Province passed the resolution 1116/QĐ-CTUB had a great impact on the land use changes in the Ca Mau. The major reasons of this conversion include the policies mentioned above, the salt intrusion issue, and the economic factor (income). Salinization, which is directly related to the expansion of aquaculture, suggests that the development of the shrimp industry might affect the environment and cause pollution (Cao et al., 2007).

The climate and environmental changes (sea level rise, storm surges and typhoons, inundation in the rainy seasons, saline intrusion in the dry seasons, etc.), the economic development and the rapid population growth, are assumed to have contributed to the observed rapid changes of land cover/land use types in the Mekong Delta in general and in the Ca Mau Province in particular.

4. CONCLUSIONS

In conclusion, the major land cover/land use categories of the Phu Tan District, for the last 30 years from 1989 to 2018, which include cultivated plants/trees, mangrove forest, aquaculture ponds, residents, and water bodies, exhibits significant changes. While the areas of cultivated plants/trees and water bodies were significantly decreased, aquaculture ponds, mangrove forest, and residential areas were greatly increased. Aquaculture ponds, mangrove forest, and residential areas were converted mainly from cultivated lands and water bodies.

These results of land cover/land use maps and change detection may be used to help in understanding the role of several factors such as socio-economic trends and environmental changes in controlling the dynamics on land use changes. Understanding the dynamics and drivers of land use change might contribute the knowledge to assist policy makers in developing useful policies for future land use planning and economic, social and environmental policies to ensure the sustainable development of this rural district.

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BIOGRAPHICAL NOTES

Hanh Hong Tran

Hanh is a lecturer and a researcher in the Department of Photogrammetry and Remote Sensing at Hanoi University of Mining and Geology. She completed her PhD in Sciences at Vrije Universiteit Brussel (Brussels, Belgium). Hanh's research interests cover a wide variety of topics at the intersection of Remote Sensing, GIS, statistic, modelling, geography, land use/land cover changes, and environment. She has published her work in about 20 international and local articles (several international journals such as Remote Sensing (MDPI), Land Use Policy, Journal of Coastal Conservation, Journal of Environmental Informatics), as well as international conference proceedings.

Viet Bach Pham

Viet is a Master of Science at AIT (Bangkok, Thailand) in 1999 on Natural Resources Management. His experience is on applications of remote sensing and GIS analysis for land cover changes, focusing on forests and urban. In the past, he worked as a researcher on ecology in the Institute Tropical Biology, then he was a lecturer of remote sensing and GIS in the Geography Faculty of HCMC USSH. Since 2005, he involved in the HCMC Institute of Resources Geography and then in the Viet Nam National Space Center as senior researcher.

CONTACTS

Title Given name and family name: Hanh Hong TRAN
Institution: Hanoi University of Mining and Geology
Address: Vien Street – Bac Tu Liem District
City: Hanoi
COUNTRY: VIETNAM
Tel. +84988150099
Email: hanhtranvub@gmail.com, hanhtran2704@gmail.com