Mangrove Mapping and Change Detection Using Multi-temporal Landsat imagery in Hai Phong city, Vietnam

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Abstract. Mangroves play an important role in protecting dyke systems and defend against the impact of tropical storms. However, these forests are under severe threat due to rapid population growth, insufficient governance, poor planning, and uncoordinated economic development. Hai Phong city is located on the Northern coast of Vietnam where the mangroves are distributed in zone I and zone II of the four mangrove zones in Vietnam. This city is vulnerable to rising sea levels associated with climate change and tropical cyclones, which are forecasted to become more prevalent and stronger as climate change intensifies. The objectives of this research were to map the locations of mangrove and to analyze their change in Hai Phong, Vietnam from 1989 to 2013 using different LANDSAT sensors including TM, ETM+ and OLI. Image segmentation was used to improve the accuracy assessment of the post satellite image processing. Moreover, Geographic Information System (GIS) and Remote Sensing data were utilized to analyze how the mangroves had changed throughout the period 1989-2013. The findings of this research showed mangrove loss from 1989 to 2001 and gain from 2001 to 2013. The overall accuracy of satellite imagery processing for the year 2013 was 83% and the Kappa coefficient was 0.81. This research indicates the potential for use of multi-temporal LANDSAT data together with image segmentation and a GIS approach for mapping mangrove forest in the coastal zone.

Keywords. Mangrove change, GIS, Satellite remote sensing, Object-based classification, Landsat imagery.

1. Introduction

Mangrove forests appear in the inter-tidal zones along the coast in most tropical and semi-tropical regions (Tuan, Oanh et al. 2002). They are among the most important and productive of ecosystems and provide habitat for wildlife (Wolanski, Brinson et al. 2009). Mangroves play an important role in coastal zones and can reduce damage from the effects of tsunamis. The most obvious evidence can be found from the Indian Ocean tsunami of Dec, 2004 (Danielsen, Sørensen et al. 2005). Moreover, mangrove ecosystems stabilize coastlines, clean water, protect land from erosion, and in many cases promote coastal accretion, and provide a natural barrier against storms, cyclones, tidal bores and other potentially damaging natural forces. For centuries, mangroves have contributed significantly to the socio-economic lives of coastal dwellers. In addition, they are a source of timber for fire-wood and provide building materials, charcoal, tannin, food, honey, herbal medicines, and other forest products (Hong and San 1993). Importantly, mangrove forests are amongst the most carbon-rich ecosystems in the tropics (Donato, Kauffman et al. 2011) and are recognized as performing a vital role in climate change mitigation thanks to "blue carbon" storage (Pendleton L 2012).

Despite their enormous socio-economic value, mangrove ecosystems are under severe threats. High population growth, and migration into coastal areas, has led to an increased demand for their products. This situation is further exacerbated by insufficient governance, poor planning, and uncoordinated economic development in coastal zones. Globally more than 3.6 million hectares of Mangroves have been lost since 1980, and Asia has suffered the greatest loss of 1.9 million hectares (FAO 2007).

Like many other countries in Southeast Asia, the mangrove areas in Vietnam have decreased markedly. In Vietnam, it is estimated that the area of mangrove forests was about 400,000 hectares in the early 20^{th} century. However, this area has declined dramatically during the past 50 years (Tuan, Munekage et al. 2003). In northern parts of Vietnam, from Mong Cai to Do Son, throughout the periods 1964-1997, mangrove area decreased by 17,094 ha. In the Red River plain, the loss of mangrove was 4,640 ha from 1975 to 1991 followed by a decrease of 7,430 ha in 1993 (NEA 2003). Despite government and international efforts in mangrove restoration programs during the 1990's, mangrove forests on the Nothern coast of Vietnam have declined significantly due to shrimp farming. Nevertheless, mangrove forests in the protected zone are well managed thanks to community-based forest management (Dat and Yoshino 2013). Thus, it is necessary to identify the location of mangroves which have changed throughout the different periods in order to support coastal management and planning programs.

Satellite remote sensing data can be used for large areas over time and thus represent an indispensable tool for mangrove forests monitoring, as coastal wetlands spread over extended and inaccessible areas. Throughout the world, many researchers have utilized various satellite remote sensing data for mapping mangrove forests using optical imagery (Long and Skewes 1996, Pasqualini, Iltis et al. 1999, Conchedda, Durieux et al. 2008, Long and Giri 2011, Nandy and Kushwaha 2011). However, in Vietnam few studies have used satellite data to analyze mangrove forest change in different periods, especially on the Northern coast. Prior research on mangrove forest using satellite data in Vietnam is limited and there is a lack of available data. Satellite remote sensing data can be used for large areas over time and thus represents an indispensable tool for mapping mangrove forests where access for survey is limited and inconvenient.

The objectives of this study are to map mangrove forests and to analyze their changes using LANDSAT imagery in Hai Phong from 1989 to 2013. In this study, an object-based method was used for different LANDSAT sensors: TM, ETM+ and OLI. In addition, a Geographic Information System (GIS) was also utilized in order to examine how the mangroves had changed throughout the different periods 1989 – 2013.

2. Materials

2.1. Study area

Hai Phong is located between 20°30' to 20°01' N latitude and 106°23' to 107°08' E longitude. This city belongs to the Northern coastal zone of Vietnam and lies within the Asian tropical monsoons belt. It borders Quang Ninh province to the north, Hai Duong province to the west, Thai Binh province to the south, and the Gulf of Tonkin to the east. It is about 120 km from the capital Hanoi. The length of the sea coast of Hai Phong is 125 km including the coast surrounding the offshore islands (Fig 1). This city has suffered from rising sea levels and tropical cyclones, which are forecasted to become more severe in coming decades.

The mangroves of Vietnam were categorized into four main zones based on geographical factors, field survey and satellite imagery (Hong 1991). Mangrove forests in Hai Phong include zone I the northeast coastal zone stretching from Ngoc Cape to Do Son cape and zone II the Northern plain coastal zone stretching from Do Son cape to Lach Truong cape (Hong and San 1993).

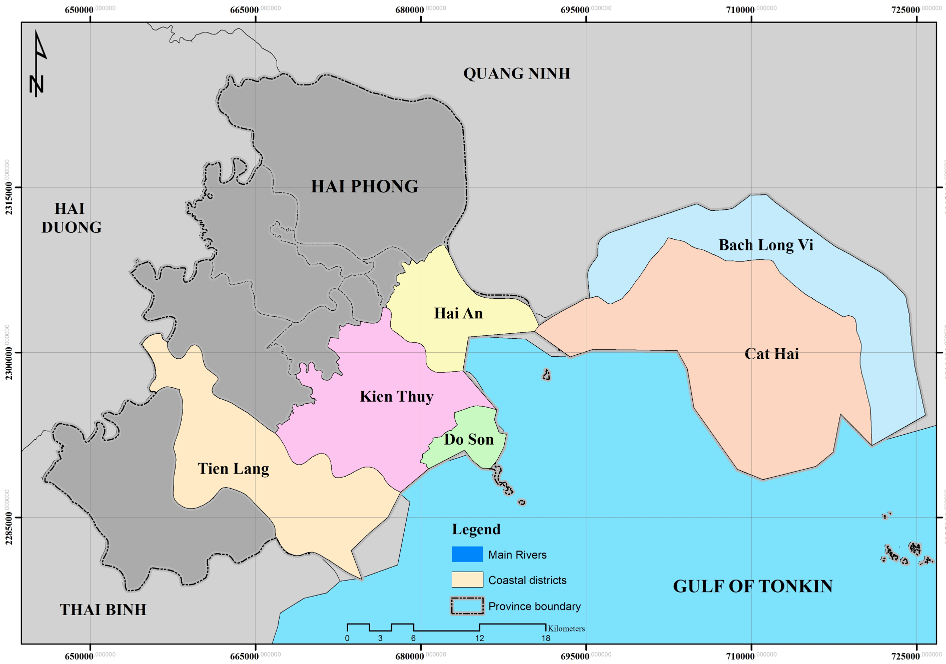

Figure 1. Location map of study area

2.2. Acquired data

2.2.1. Satellite imagery

Multi-temporal medium resolution LANDSAT imagery was used to obtain comprehensive coverage and analysis of the current and historical mangrove conditions. The used imagery was acquired by several different satellite sensors including LANDSAT TM/ETM+, LANDSAT 8 (Table 1).

LANDSAT TM and ETM+ images were acquired from the Global Land Cover Facility, the University of Maryland (*http://www.glcf.umd.edu/data/landsat/*).

LANDSAT OLI image was acquired from the USGS, NASA from glovis (http://glovis.usgs.gov/).

Satellite sensor	Date of acquisition	Pixel size	Spectral resolution	Band used
Landsat OLI	2013/09/22	30 m	Multi-spectral (11 bands)	3, 4, 5, 6
Landsat ETM+	2001/09/29	30 m	Multi-spectral (6 bands)	2, 3 ,4, 5
Landsat TM	1989/11/23	30 m	Multi-spectral (6 bands)	2, 3, 4, 5

Table 1. Acquired satellite remote sensing data

2.2.2. Field survey data

The field data was collected during several field trips carried out during January, May, October 2008, March 2009 and July, August 2011 and September 2014. The former dataset was used for a land cover map for 2001 and the latter dataset was used to generate a map in 2013. The foundation for these field trips was the collection of land cover information in particular mangrove forests. Five coastal districts were visited in Hai Phong and we collected ground-truth points using GPS (Global Positioning Systems) to create training data for supervised classification and generate accuracy assessment for the post classification of the land cover map in 2013.

3. Methodology

3.1. Image classification of Landsat imagery

The image classification approach of Landsat imagery can be divided into the following main steps:

Geometric rectification: All data were geometrically rectified to UTM coordinates (Datum: WGS84, Zone 48 North) using image-to-image registration with data from NASA's global orthorectified LANDSAT archive acting as a reference. Rectification was based on a nearest neighbor resampling routine and in all instances the root-mean-square error was less than one pixel.

Segmentation: After geometric rectification, the classification was passed on and an image segmentation procedure was initiated (Giri et al., 2007b). Image segmentation is the basic processing unit in object-based classification or an object-oriented approach (Dehvari and Heck 2009). The segmentation process divides the image into homogenous objects, based on three parameters scale, color (i.e. spectral information) and shape.

Supervised classification: After image segmentation, the data set obtained from the field survery was used to create training data for the classification of LANDSAT 8 imagery. LANDSAT 8 imagery was classified using a supervised training method by applying maximum livelihood algorithms (Jensen 1996). ENVI 5.2 software was also employed for imagery processing. Seven categories of land cover for 2013 were classified: mangrove, forest, rice paddy, aquaculture, water bodies, bareland and settlement. The ground truth data obtained from the field survey in September 2014 was used to generate accuracy assessment for the post processing of the LANDSAT 8 imagery.

Manual correction: This step was carried out utilizing GIS tools. GIS allows the update of data based on fieldwork during September 2014 and may act as a tool for enforcing mangrove conservation (Dahdouh-Guebas, Zetterström et al. 2002). In a subsequent step, manual editing of the child objects is easily facilitated in a GIS where the segments can be shown along with the image data. From visual inspection it is then straightforward to recode any falsely classified child object back to its actual class.

Quality check: After manual correction, the classification was sent for a quality check. If the classification passed this check it was recorded as one cover type, otherwise it was returned for further editing. Part of the quality checking also included a formal accuracy assessment where verification objects from each class were extracted randomly and their land cover labeled by an external analyst from visual interpretation of available VHR data from Google Earth. Hereafter, the land cover classification was evaluated using standard measures of accuracy assessment (Congalton and Green 1999) and the pixels residing inside the verification objects as reference. Google Earth VHR data used for 2013 was available for improving the accuracy of the land cover map.

It is noted that the historical mangrove forest mapping for 1989 and 2001 (LANDSAT TM/ETM+) used a somewhat simpler classification approach starting with image segmentation and followed by manual labeling of all mangrove objects.

The figure below represents an example of image segmentation for both LANDSAT TM, ETM+ and LANDSAT 8 imagery in Hai Phong. The composite RGB was created before running segmentation based on three different bands (Mid-infrared, Near-infrared, and Red) for LANDSAT TM and ETM+ imagery (band 5-4-3) and (band 6-5-4) for LANDSAT 8 imagery (Fig 2).

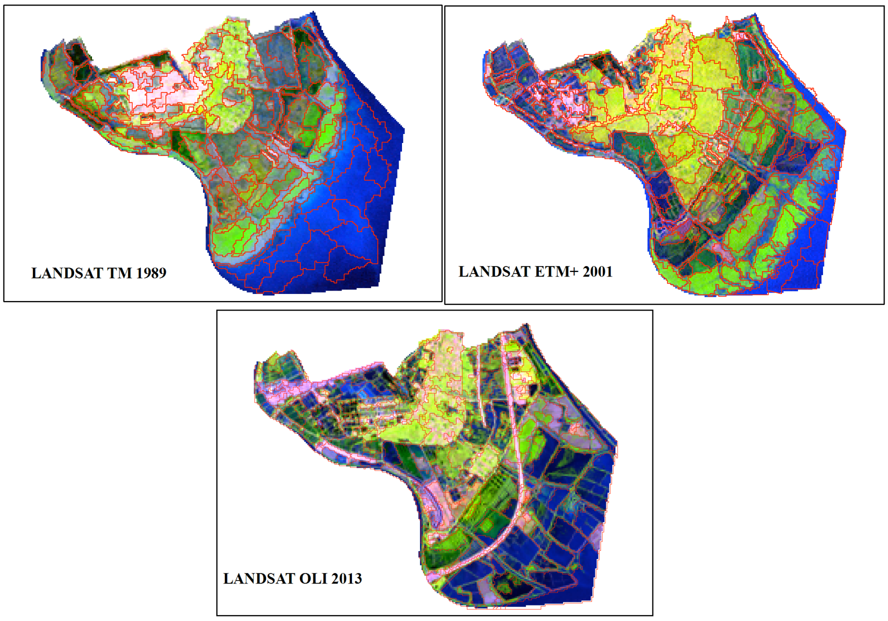

Figure 2. Example of image segmentation

Finally, three different periods were overlaid in ArcGIS version 10.2 to detect mangrove forest change between 1989 and 2013. The whole image processing is illustrated in figure 3.

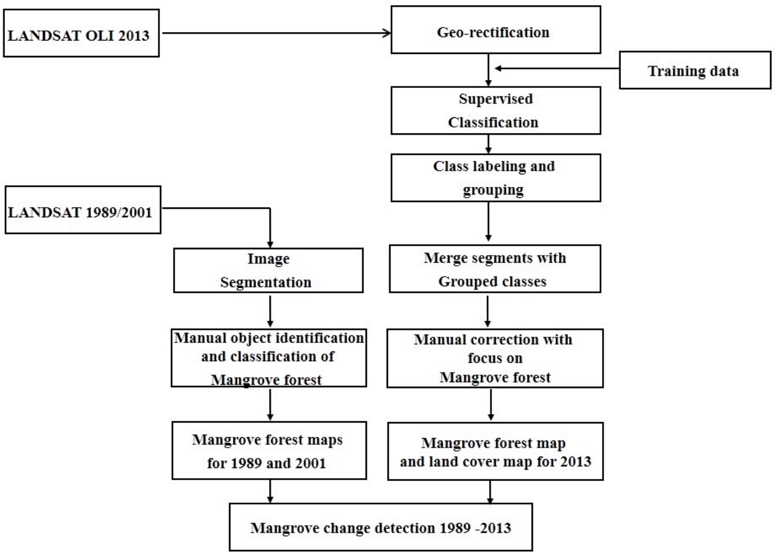

Figure 3. Flowchart of the image processing and change detection approach

4. Results and discussion

4.1. Mangrove mapping

The figures below represent the land cover map for 2013 in Hai Phong and a map of mangrove forest change from 1989 to 2013.

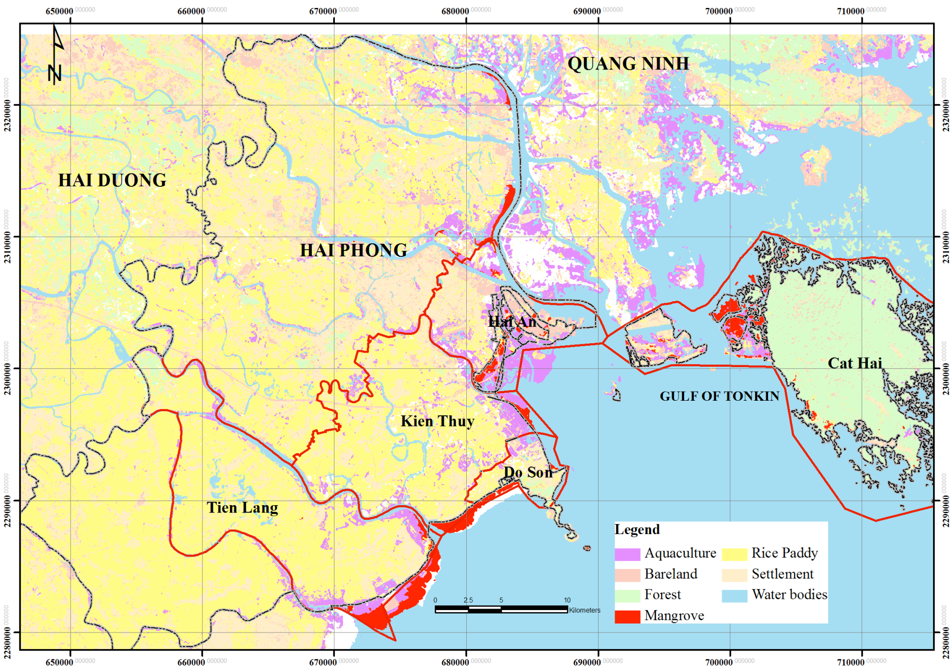

Figure 4. Land cover map for the year 2013 in Hai Phong

The overall accuracy and the Kappa coefficients of the satellite image processing are shown in table 2.

The overall accuracy of satellite imagery processing using LANDSAT 8 for the year 2013 is 84%, and the Kappa index is 0.81.

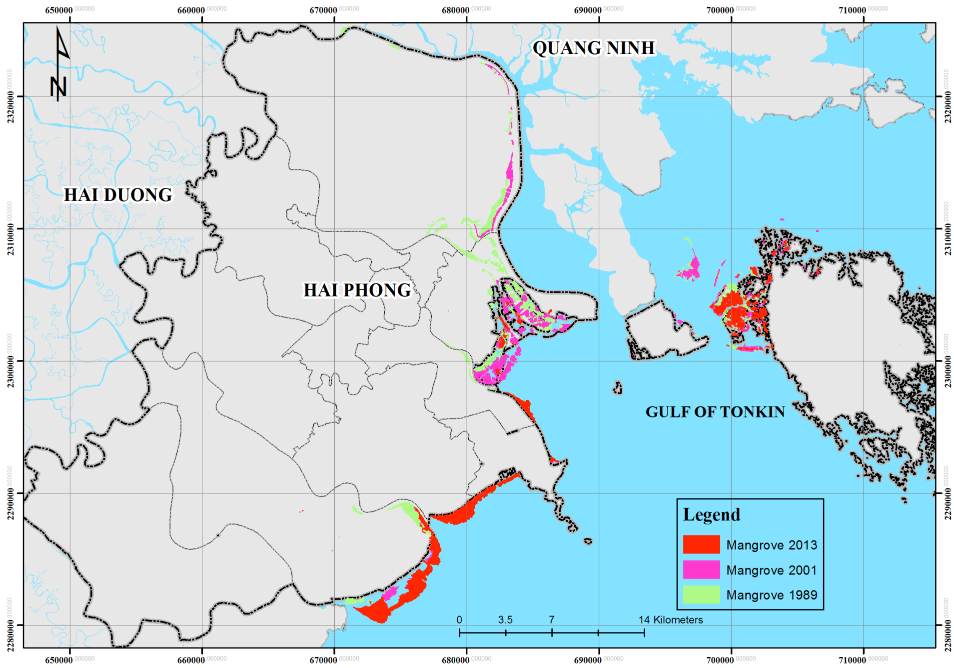

Figure 5. Mangrove forests change map in Hai Phong from 1989 to 2013

	Ground Truth (Points)							
Landcover	AQ	BL	FR	MG	RP	SL	WB	Total
AQ (Aquacul-ture)	22	2	0	1	1	0	0	**26**
BL (Bareland)	0	13	1	0	0	2	0	**16**
FR (Forest)	0	0	12	3	0	0	0	**15**
MG (Mangro-ve)	4	0	0	36	0	0	0	**40**
RP (Rice Paddy)	1	2	0	3	23	3	0	**32**
SL (Settle-ment)	1	3	0	0	0	40	0	**44**
WB (Water bodies)	3	1	0	0	0	0	15	**19**
Total	**31**	**21**	**13**	**43**	**24**	**45**	**15**	**192**
Pro. Accuracy	70.97%	61.90%	92.31%	83.72%	95.83%	88.89%	100%	Overall Accu.
User Ac-curacy	84.62%	81.25%	80.00%	90.00%	71.88%	90.91%	18.95%	**83.85%**

Table 2. Accuracy assessment of the land covers classification for 2013

By overlaying past mangrove forest cover with current land covers within the ArcGIS environment, it is possible to get an indication of what land cover is currently present in areas formerly occupied by mangroves. In doing so, we can determine if that the past mangrove forest cover has been converted into aquaculture, which a common trend throughout South East Asia (Giri et al. 2007a). However, a large area of former mangrove is currently classified as water or aquaculture. The latter is interesting since mangroves can be rehabilitated and restored relatively easily in these areas and without economic conflict if aquaculture were to be reintroduced into the mangroves.

4.2. Mangrove forests change from 1898 to 2013

The mangrove forest area declined by 8% between 1989 and 2001 while this figure increased by 9% after over two decades. The change statistics indicates that Hai Phong lost 281 hectares of mangrove forests over ten years and gained roughly 355 hectares after twenty four years. The annual rate of mangrove loss in Hai Phong was approximately 23 hectares (Table 3) during the first period 1989-2001. From 2001 to 2013, mangrove gained about 53 hectares per year.

This was due to the Doi Moi economic reform in Vietnam that was established in 1986. The Vietnamese economy was transformed into a market economy (Hue 2001). Shrimp farming for export was encouraged and promoted by the government. As a consequence, mangrove areas were converted to shrimp aquaculture because of the high benefit from shrimp exports (Tuan et al., 2003). In over one decade, many regions were converted to shrimp aquaculture ponds destroying significant mangrove forest in Vietnam (Seto and Fragkias 2007).

Period	Mangrove area at onset of period (ha)	Mangrove area at end of period (ha)	Mangrove area change (ha)	% change	Annual rate of gain/loss (ha yr^{-1})
1989-2001	3534 ± 323	3253 ± 370	-281	-8.0	-23
2001-2013	3253 ± 370	3889 ± 308	636	16	53
1989-2013	3534 ± 323	3889 ± 308	355	9	15

Table 2. Mangrove changes in Hai Phong from 1989 to 2013.

On the other hand, from 2001 to 2013, mangrove forests increased slightly since some coastal districts had a good mangrove conservation system in place thanks to community-based forest management (Hue 2008) in cooperation with local authorities (Dat and Yoshino 2013). This situation occurred in Hai Phong after three severe tropical cyclones named Washi, Vincente, and Damrey attacked its coastal zone in 2005. In dense mangrove forested areas there was no damage; however, areas converted to shrimp aquaculture from mangrove forest by local people were devastated in 2005. After 2005, people realized the important role of mangrove in protecting the dyke system and their livelihood. They planted mangrove again in vulnerable areas to defend against the typhoons.

The analysis of mangrove changes from 1989 to 2013 using LANDSAT indicates that in the Northern coast of Vietnam in general and Hai Phong city in particular, mangrove forests have increased slightly. In order to promote mangrove forests conservation and a management program to support REDD+ mechanism in Vietnam, a long-term strategy is needed fulfil the important role of mangrove forest conservation in dealing with climate change mitigation and adaptation into consideration.

In this research, we tried to accommodate this uncertainty by operating with two sub-classes when calculating the area statistics. These are closed mangrove areas where the mangroves appear visually strong in the satellite imagery and secondly, open mangrove areas where the signal is less significant (Giri et al., 2007b). In the final area statistics we provide a combined area estimate given by the closed mangrove plus half the sum of the closed mangrove and the open mangrove. This total area estimate is supplemented by an error estimate that is given by half of the difference between the closed mangrove and the open mangrove (Table 2). In more simple terms, it means that the area estimate is somewhere in between the total area of the closed mangrove and the area defined by the closed mangrove as well as the open mangrove. The final classification shows the area distribution of mangrove forests in Hai Phong.

Thus the maps and statistics illustrate the value of LANDSAT imagery in providing a synoptic view of mangrove changes that can be used for prioritising mangrove protection and rehabilitation in the region. This map also updates the status of mangrove forests in one of the most important coastal cities on the Northern coast of Vietnam. It is clear that, LANDSAT 8 has the potential for mapping mangrove forest on a regional scale.

5. Conclusions

Remote sensing was the practical approach used to map and observe mangrove forest change along the coast of Hai Phong, whilst GIS facilitated the integration and analysis of the mangrove forest with thematic and biophysical maps of the coastal zones.

It is important to emphasize that mangrove mapping and change detection represents a difficult endeavour both as an automatic classification exercise and for visual interpretation. In the ideal case of dense tall mangrove the classification is straightforward but when the stand height lowers and/or the density of the mangroves is lower becomes prone to errors. This is further exaggerated by the varying tide levels - both within and between years used for this study. Therefore, we tried to choose the same seasonal period of LANDSAT imagery to minimize the error of tidal level and rice paddy season.

For the image classification, the LANDSAT 8 sensor used for the 2013 provides quite high overall accuracy and Kappa coefficient in mapping land-cover and mangrove forests. Therefore, LANDSAT 8 should be used for mapping mangrove forest on national and regional scales.

This research indicates the potential for using multi-temporal LANDSAT data together with image segmentation and a GIS approach for mapping mangrove forests in coastal zones. In addition, the statistical results of this research are important as a valuable reference to understand the current condition of mangrove forests in a coastal city in the Northern part of Vietnam.

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