MONITORING MANGROVE FOREST USING MULTI-TEMPORAL SATELLITE DATA IN THE NORTHERN COAST OF VIETNAM

*Pham Tien Dat *[a] and Kunihiko Yoshino [b]*

[a] *Graduate student, Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8577 Japan; Tel: +81-29-853-5577; E-mail: dat6784@gmail.com*

[b] *Professor, Graduate School of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8573 Japan; Tel: +81-29-853-5005; E-mail : sky@sk.tsukuba.ac.jp*

KEY WORDS: Mangrove change, GIS, Satellite remote sensing, Object-based classification, Vietnam.

ABSTRACT: The vast majority of population in Vietnam lives in the lowland and near the coastal areas, which are vulnerable by rising sea level and tropical cyclones. Mangrove forests play a vital role to protect dyke systems and prevent shoreline erosion as well as defend the impact of storms and flood risk. Nevertheless, these forests are under severe threat due to the rapid growth of population, intensive shrimp and crab rearing as well as migration into the coast. The objective of this research was to analyze mangrove changes using different sensors in the Northern Vietnam from 1990 to 2006/07. Satellite based mapping is used to detect mangrove changes. Object-based classification was used to improve accuracy assessment of post satellite image processing. Moreover, Geographic Information System (GIS) and Remote Sensing data were applied for analyzing how the mangrove changes throughout the different periods 1990 – 2006/07. The finding of this research showed that over 95% of the mangrove is located within the four provinces of Quang Ninh, Hai Phong, Nam Dinh, Thai Binh and with Quang Ninh province alone holding about 60% of the total Mangrove cover in northern Vietnam. Mangrove loss was approximately 2700 hectare of which Quang Ninh and Hai Phong contributed 4566 and 1101 hectare, respectively. Nevertheless, mangroves have expanded in Thai Binh and Nam Dinh thanks to good mangrove rehabilitation and plantation programs in Xuan Thuy National Park. The overall accuracy of satellite imagery processing for the year 2006 and 2007 was 89%, the Kappa index was 0.87. The research may provide appropriate solutions for mitigation and adaptation to climate change through improved management of mangroves along the coast of Vietnam.

1. INTRODUCTION

Much of Vietnam, over 75% is mountainous; however, the vast majority of population lives near the coast. These areas are threatened by rising sea levels associated with climate change, and are already frequently visited by tropical storms, which are forecast to become more prevalent and stronger as climate change intensifies.

Mangrove forests appear in the inter-tidal zones along the coast in most tropical and semi-tropical regions (Tuan et al., 2002). They are among the most important and productive of ecosystems and are found along the coastal zones and offshore islands. Mangroves play an important role in coastal zone and can reduce the damage from the effects of Tsunami. The most obvious evidence could be found in Indian Ocean tsunami in Dec, 2004 (Danielsen et al., 2005). Moreover, mangrove ecosystems stabilize coastlines, clean water, protect the land from erosion, and 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; Tuan et al., 2002).

Nevertheless, mangroves are under severe threat. High population growth, and migration into coastal areas, has led to an increased demand for its services. The situation is further exacerbated by weak governance, poor planning and uncoordinated economic development in the coastal zone. Globally more than 3.6 million hectares of Mangroves has been lost since 1980. Asia has suffered the greatest loss of 1.9 million hectares (FAO 2007). Like many other countries in Southeast Asia, the mangrove area in Vietnam has decreased markedly. In Vietnam, it is estimated that the number of mangrove forest was about 400,000 hectares in early 20th century. However, this number declined dramatically over 50 years (Tuan 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 then followed by a decrease of 7,430 ha in 1993 (NEA, 2003). The coastal zone of Southern Viet Nam witnessed little change of mangroves (from 250,000 ha to 210,000 ha) during 1950 - 1960; yet, the figure reduced to 92,000 ha of mangroves in 1975 due to the spraying of warring herbicides by the American force (1962 – 1972) (Tuan et al., 2002). Therefore, it is necessary to monitor mangrove forest, and mapping of mangroves is important in order to support coastal zone management and planning programs.

In Vietnam, Cuc (2004) used GIS for estimating planting suitable areas for each mangrove species. However, few studies have applied the satellite data for monitoring mangrove forest. Satellite data can be used for large areas as well as through time and thus represent an indispensable tools for mangrove forest monitoring, as coastal wetlands distribute over extended and inaccessible areas. In this paper, the satellite-based data were used for analyzing mangroves change along the coast of Northern regions in Vietnam from 1990 – 2006. We propose long term strategies to protect and improve the livelihood of people living in the lowland in the coastal areas in Vietnam.

2. STUDY AREA

In Vietnam, Phan Nguyen Hong has categorized the mangroves into 4 main zones based on geographical factors, field survey and satellite imagery (Hong, 1991). The study site includes zone I named northeast coastal zone stretches from Ngoc Cape to Do Son cape, zone II named the coastal zone of Northern plain stretches from Do Son cape to Lach Truong cape in which has existed a Xuan Thuy RAMSAR that has recorded as a National Park since 2003 and partly zone III named the coastal central zone stretches from Lach Truong cape to Vung Tau (Hong and San, 1993).

The study site has focused on the eight coastal provinces in Northern Vietnam: Quang Ninh, Hai Phong, Thai Binh, Nam Dinh, Ninh Binh, Thanh Hoa, Nghe An and Ha Tinh. This area has a single uniform type of dyke system and the management strategy for this coastal area is uniform. There are three provinces located in the Red River Delta including Thai Binh, Nam Dinh and Ninh Binh.

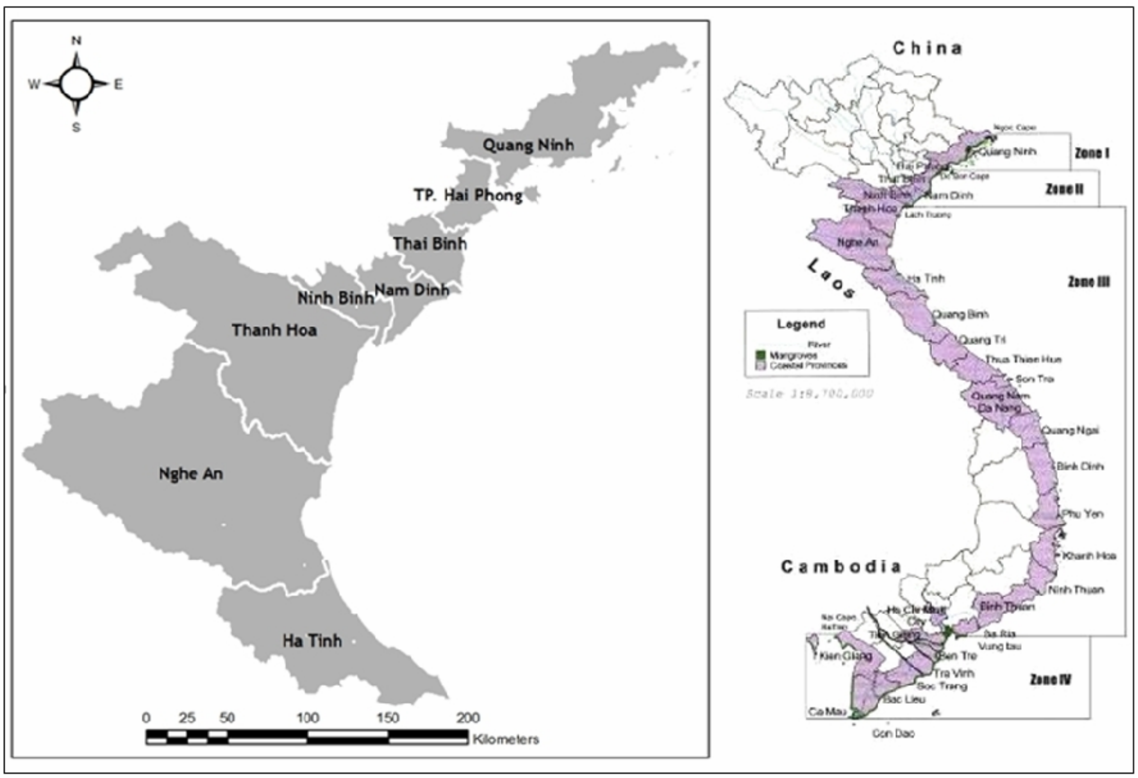

Figure 1: Location map of study areas

3. DATA AND METHODOLOGY

3.1. Acquired data

Satellite imagery

A multi-resolution and multi-temporal approach relying on both medium and high-resolution satellite imagery was used to obtain a comprehensive coverage and analysis of the current as well as historical situation. The imagery used was acquired by several different satellite sensors including SPOT4, LANDSAT TM/ETM+ (see Table 1).

Table 1: Acquired satellite remote sensing data.

Satellite sensor	Date of acquisition	Spatial resolution	Spectral resolution
SPOT4	2006/2007	20 m	Multi-spectral (4 bands)
LANDSAT ETM+	2000/2001	30 m	Multi-spectral (6 bands)
LANDSAT TM	1989/91/92/93	30 m	Multi-spectral (6 bands)

Field survey data

The field data has been collected during several field trips carried out over the lifetime of this research (in January, May, October 2008, March 2009 and July, August 2011). The foundations for these field trips have been the collection of land cover information in particular mangrove forest. There are five provinces that have been visited and we collected ground-truth data for accuracy assessment.

3.2. Methodology

The image classification approach 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 instanced the root-mean-square error was less than one pixel.

Unsupervised classification

The geo-referenced 2006/07 SPOT images were classified into 50 spectral classes using an unsupervised ISODATA classification algorithm (Jensen, 1996). The spectral classes were then thematic coded according to a predefined classification scheme and when applicable using available reference material e.g. field data and/or Google Earth.

Segmentation

After unsupervised classification and labeling the classification was passed on and an image segmentation procedure was initiated (Giri et al., 2007b). Image segmentation is the basic processing units in object-based classification or object-oriented approach (A.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. Segmentation process is run so that it respects the class boundaries of the unsupervised classification and thereby child objects to the unsupervised classes are generated. There are thirteen land cover types: mangrove, forest, shrubland, grassland, cropland, rice paddy, aquaculture, bare soil, water, tidal mudflat, settlement, salt pans and cloud.

Manual correction

This step is carried out based on GIS tools. GIS allows to update more data based on the fieldwork and may act as a tool for enforcing mangrove conservation (Dahdouh-Guebas 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 checking

After manual correction the classification was send on for 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 was extracted randomly and their land cover were 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 was only available from a restricted area, however, considering the relatively broad classes and consistency of the methodology applied, the accuracy of the land cover map are deemed to be of the same order as inside the verification area.

The whole image processing has been illustrated in the Figure 2. Note that as for the historical mangrove forest mapping a somewhat simpler classification approach was used starting with image segmentation and followed by manual labeling of all mangrove objects.

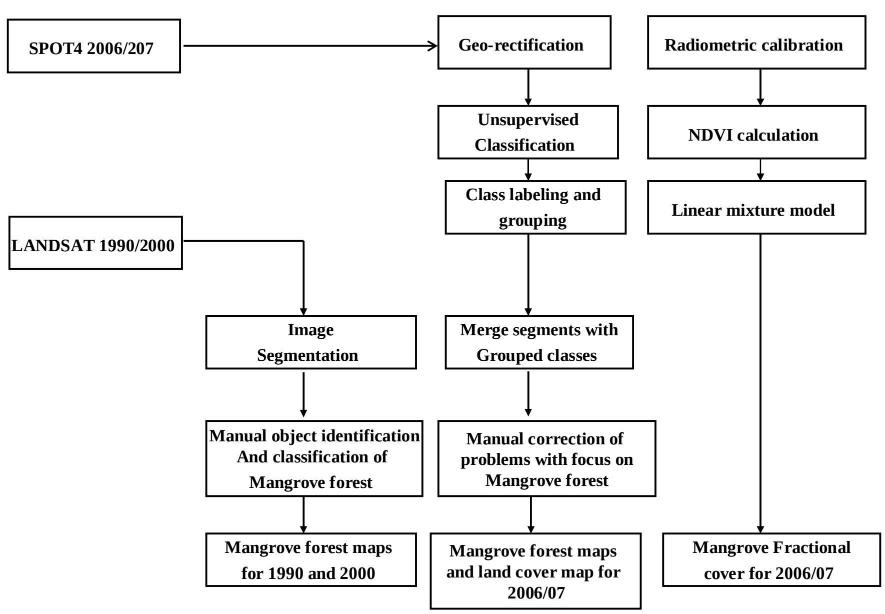

Figure 2: Flowchart of the processing and classification of acquired satellite imagery

4. RESULTS

The first finding of this research shows that approximately 95% of the mangrove is located within the four provinces of Quang Ninh, Hai Phong, Nam Dinh and Thai Binh. In Quang Ninh province, it is alone holding about 60% of the total mangrove cover in northern Vietnam.

The change statistics indicates that on average, the eight provinces lost 2,700 ha of mangrove forest of a total area around 25,000 ha in 1990. In relative numbers in means the region experienced an 11% overall (or 0.65% annually) loss of mangroves between 1990 and 2007 (Table 2). In this research, we have tried to accommodate this uncertainty by operating with two sub-classes calculating the area statistics. Firstly, 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 then 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 the half of the difference between the closed mangrove and the open mangrove. In more simple terms it means 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 forest and other land cover in northern Vietnam.

In addition, this average trend reveals a significant geographical variation as the loss of mangroves in Quang Ninh and Hai Phong alone exceeds 4,500 hectares whereas Thai Binh and Nam Dinh have contributed with a 2,500 hectare increase in mangrove forest thanks to historical conditions, the Xuan Thuy National Park is an original sources of mangrove plantation with *Kandelia abovata*. Thus the maps and statistics illustrate the value of satellite imagery in bringing about a synoptic view of the mangrove changes that can be used for prioritising mangrove protection and rehabilitation in the region.

The overall accuracy of satellite imagery processing for the year 2006/07 is 89%, Kappa index is 0.87 (See table 3). The outcome of the accuracy assessment showed a high correspondence between the classified objects and the reference data indicating the produced maps provide reliable information about the mangrove forest as well as other land cover classes in the project area. Classification errors, however, is inevitable due to the gradual transitions and spectrally similarities between certain classes (e.g. mangroves vs. mudflats, grassland vs. bare land and forest vs. shrubland). The latter will among others manifest itself in scene to scene variations of the resulting outputs as spectrally similarities may be higher at certain times of year than in others. Finally, it was impossible to avoid a certain operator bias since all skilled operators was involved in the production of the land cover map, and therefore we expect the accuracies to be somehow biased against the higher end.

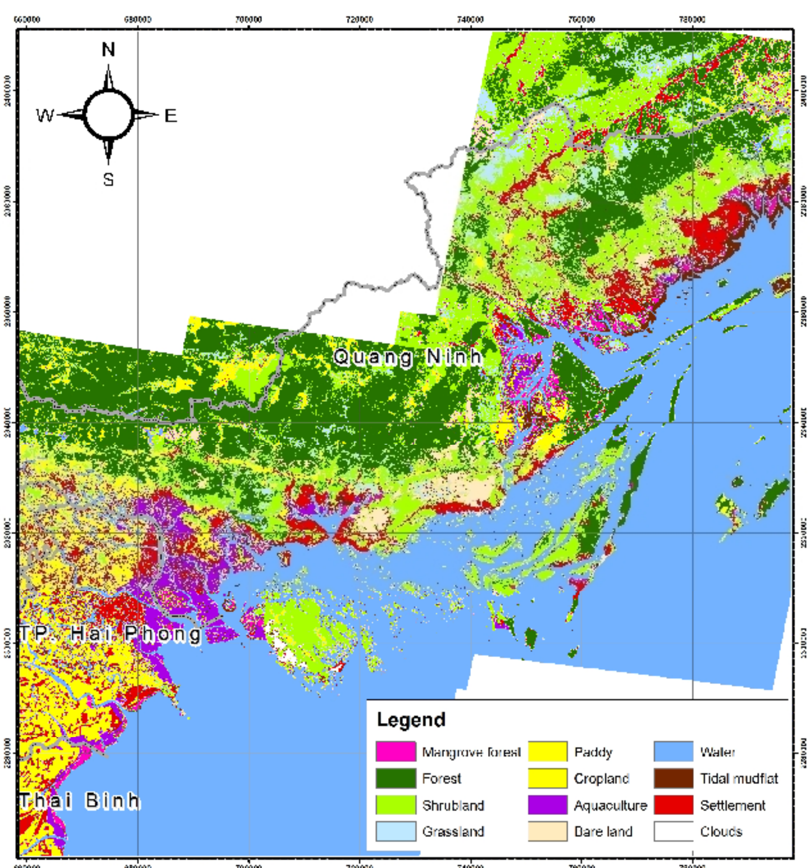

Figure 2: Land cover map for 2006/07

Table 2. Per-province Mangrove area statistics.

	1990		*2000*		*2007*		*Change*	*Change*	*Change*
Province	***Area (ha)***	***% to Total***	***Area (ha)***	***% to Total***	***Area (ha)***	***% to Total***	***1990 to 2000***	***2000 to 2007***	***1990 to 2007***
Ha Tinh	77 ±5	0.31%	88 ±27	0.36%	386 ±16	1.69%	11	299	309
Hai Phong	3534 ±323	14.00%	3253 ±370	13.34%	2433 ±103	14.06%	-281	-820	-1101
Nam Dinh	1100 ±168	4.36%	2106 ±630	8.64%	2353 ±99	10.29%	1006	246	1253
Nghe An	94 ±2	0.37%	58 ±28	0.24%	225 ±28	0.99%	-36	167	131
Ninh Binh	139 ±3	0.55%	140 ±24	0.58%	270 ±97	1.18%	1	130	131
Quang Ninh	18790 ±3669	74.45%	16268 ±1886	66.72%	14224 ±2839	60.22%	-2522	-2044	-4566
Thai Binh	1447 ±191	5.73%	2347 ±468	9.62%	2434 ±145	10.64%	900	87	987
Thanh Hoa	56 ±31	0.22%	124 ±32	0.51%	212 ±94	0.93%	68	89	156
Total	***25238*** *±4692*	*100.00%*	***24384*** *±3463*	*100.00%*	***22874*** *±3505*	*100.00%*	***-854***	***-1846***	***-2700***

Table 3: Accuracies assessment of the 2006/07 land cover classification

	Reference data											
Classified	Cropland	Settlement	Grassland	Forest	Shrubland	Aquaculture	Bare land	Water	Mangrove	Mudflat	Row total	User's acc.
Cropland	**2835**	261	0	0	1	0	0	0	0	0	3097	91.54%
Settlement	0	**1974**	0	0	0	141	0	0	6	0	2121	93.07%
Grassland	457	175	**1169**	0	208	0	787	0	0	0	2796	41.81%
Forest	0	0	0	**3166**	0	0	0	0	0	0	3166	100.00%
Shrubland	0	15	11	152	**2506**	0	0	0	0	0	2684	93.37%
Aquaculture	0	0	0	0	0	**5798**	0	0	3	0	5801	99.95%
Bare land	0	217	152	0	247	0	**2073**	0	0	0	2689	77.09%
Water	0	0	0	0	0	0	0	**8350**	0	147	8497	98.27%
Mangrove	0	0	0	0	0	195	0	0	**3141**	0	3336	94.15%
Mudflat	0	0	0	0	0	0	0	761	231	**2688**	3680	73.04%
Column total	3292	2642	1332	3318	2962	6134	2860	9111	3381	2835	***37867***	
Producer's acc.	86.12%	74.72%	87.76%	95.42%	84.60%	94.52%	72.48%	91.65%	92.90%	94.81%		

4. Discussion & Conclusion

Remote sensing was the practical approach to map and observe the extent and evolution of mangroves along the northern coast of Vietnam, whilst GIS facilitated the integration and analysis of the mangrove forest with thematic and biophysical maps of the coastal zone.

By overlaying the past mangrove forest with the current land cover, it is also possible to get an indication of what land cover is currently present at areas formerly occupied by mangroves. In doing so we can see that for the most part the past mangrove forest cover has been converted into aquaculture, which a common trend throughout South East Asia (Giri et al. 2007a). However, there is also a large part of the former mangrove which is currently classified as water or mudflats. The latter is interesting since mangroves could be rehabilitated and restored relatively unproblematic in these areas and without the economic conflicts involved if aquaculture were to be restored back to mangroves.

As for the mangrove mapping and monitoring it is important to emphasise that it represent a difficult endeavour both as an automatic classification exercise but also in terms of visually interpretation. In the ideal case of a dense tall mangrove the classification is straightforward and correct but when the stand height lowers and/or the density of the mangroves lower then interpretations starts to be prone to errors. This is further exaggerated by the varying tide levels - both within and between years - as present in the multitude if satellite images used for this project. A further problem comes from the difference in the spatial resolution of the involved sensors. The SPOT4 sensor used for the 2006/07 mangrove classification has a resolution of 20 meters whereas the Landsat data used for the historical tracking of mangrove forest has a resolution of 30 meters. While the SPOT and Landsat sensor on a general level do provide comparable images then the better detail of SPOT will occasionally reveal mangrove information that cannot be depicted by the Landsat sensor e.g. when mangroves forms as narrow strips along the river mouths.

In the Northern coast of Vietnam, in general mangrove forests have decreased dramatically after analyzing mangrove changes from 1990 to 2006/07 based on satellite remote sensing data. This situation has occurred since many mangrove regions were converted to shrimp farming due to the high benefit from shrimp exports (Tuan et al., 2003). In less than one decade, there were many regions have been converted to shrimp aquaculture ponds destroying significant mangrove forest in Vietnam (Seto and Fragkias, 2005). In order to solve this problem, it should be applied a long-term strategy to improve local livelihood of people through the effective use of mangrove ecosystems.

REFERENCES

A.Dehvari & Heck, A. R. J. 2009. Comparison of object-based and pixel based infrared airborne image classification methods using DEM thematic layer. Journal of Geography and Regional Planning, 2, 086-096.

Congalton, R.G., Green, K., 1999. Assessing the Accuracy of Remotely Sensed Data—Principles and Practices. Lewis Publishers, New York**.**

Cuc, N. T. K., 2004. The application of GIS to the management of mangrove plantations at Giao Thuy district. In: Mangrove ecosystem in the Red River coastal zone: biodiversity, ecology, socio-economic, management and education. Agricultural Publishing House, Hanoi, 347-355.

Danielsen, F., Sørensen, M. K., Olwig, M. F., Selvam, V. & et al., 2005. The Asian Tsunami: A Protective Role for Coastal Vegetation. Science, 310**,** 643.

Dahdouh-guebas, F., Zetterström, T., Rönnbäck, P., Troell, M., Wickramasinghe, A. & Koedam, N. 2002. Recent Changes in Land-Use in the Pambala–Chilaw Lagoon Complex (Sri Lanka) Investigated Using Remote Sensing and GIS: Conservation of Mangroves vs. Development of Shrimp Farming. Environment, Development and Sustainability, 4**,** 185-200.

FAO, 2007. The World's mangroves 1980-2005. A thematic study prepared in the framework of the Glob5al Forest Resources Assessment 2005. FAO Forestry Paper. Rome: Food and Agriculture Organization of the United Nations.

Giri, C., Zhu, Z., Thieszen, L. L., et. al., 2007a. Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. Journal of Biogeography.

Giri, C., Pengra;, B., Zhu;, Z., Singh;, A. & Tieszen;, A. L. L, 2007b. Monitoring mangrove next term forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuarine, Coastal and Shelf Science, 73, 91-100

Hong, P. N. 1991. Ecology of mangrove vegetation in Vietnam. Doctor, Hanoi Pedagogic University.

Hong, P. N. & San, H. T. 1993. Mangroves of Vietnam. IUCN. Bangkok, Thailand.

Jensen, J. R., 1996. Introductory Digital Image Processing: A Remote Sensing Perspective, (2nd Edition), Prentice-Hall, Inc.: Saddle River, NJ, 316 p.

NEA, 2003. Strategies for Wetland Management in Vietnam.

Seto, K.C. & Fragkiasc, M., 2007. Mangrove conversion and aquaculture development in Vietnam: A remote sensing-based approach for evaluating the Ramsar Convention on Wetlands. Global Environmental Change, 17, 486–500.

Tuan, L. D., Oanh, T. T. K., Thanh, C. V. & Quy, N. D. 2002. Can Gio Mangrove Biosphere Reserve, Ho Chi Minh city, Agricultural Publishing house.

Tuan, L. X., Munekage, Y., Dao, Q. T. Q., Tho, N. H. & Dao, P. T. A. 2003. Environmental Management in Mangrove Areas Environmental Informatics Archives, 1, 38-52.