Technical Letter

Using Remote Sensing Techniques for Coastal Zone Management in Halong Bay, Vietnam

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Abstract

Coastal zones consist of many fragile ecosystems, in particular, mangrove ecosystems are very sensitive and highly vulnerable. The pressure of increasing population and development has caused a significant proportion of the mangroves to be destroyed. The Halong Bay area is a famous World Heritage site, well known for its biodiversity. However, in recent years, the mangrove ecosystem in this area became degraded. Monitoring the changes of mangrove cover and coastline can provide support for coastal zone management and environmental protection of the bay.

Reliable and timely information is therefore required in order to monitor and manage the remaining mangrove resources. The analysis applied integrated techniques of digital image processing: The Normalized Difference Vegetation Index (NDVI) was computed for each date of imagery to derive variations in the vegetation biomass. The interactive stretching techniques helped to detect the range of mangrove from the NDVI image of three dates of Landsat satellite imagery. The Digital Elevation Model (DEM) and moisture indices was also integrated in the logical analysis to support the seperability tidal wetland, and mangrove from vegetation in the inland. Change detection methods were used to calculate the change in mangrove forest cover and coastal zone area over time. The analysis used three different Landsat TM scenes from 1988, 1998 and 2002, and combined results with survey data from 2002. Degraded and rehabilitation mangrove area was quantified by applying an ISODATA unsupervised classification of the RGB-NDVI image. The results show that area of mangroves have been reduced by 21% for aquaculture and tidal wetland was replaced by reclamation, which also gave impact to the coast line and changes the landscape of the bay. The results presented here illustrate the impact of development in recent years and support for coastal zone management.

1. Introduction

Coastal zone management is an important task in coastal and marine management, which promotes sustainable development practices, and it is useful to manage emerging sector conflicts in areas with high development potential, such as Halong Bay area (northeastern Vietnam). Coastal ecosystems, especially mangroves, are rich in biodiversity, but they are easily destroyable by both natural and human impacts. Mangroves represent a specific ecosystem found in

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the intertidal zone along the coastline. They are often located near estuaries and deltas. Being highly productive ecosystems and harboring a large diversity of species adapted to these particular habitats, they are considered to be ecologically important. Especially in Halong Bay, the mangrove ecosystem plays an important role for the bay's protection. In recent years, due to industrial activities and tourism development, the Halong city has changed rapidly. Expanding space used for new planning areas means reclamation to the coastal zone for settlements, transport infrastructure, deepsea port construction and also the development of intensive aquaculture. These activities have a serious impact to the ecosystem. They reduce the area of mangroves, changing the coastline and the wetland environment in the estuary and coastal zone area.

Tools like Remote Sensing (RS) and Geographical Information System (GIS) can generate data required for planning of coastal management on a sustainable basis. GIS is a very useful tool for mapping and monitoring of coastal resources and can help in assessing changes in coastal environmental conditions due to human interference. Satellite sensors are likely to be a rather cost-effective methodology. Remote sensing data, especially Landsat Thematic Mapper (TM) data have been proven to be extremely useful for wetland mapping as well as for delineation of high and low water lines; also by applying the NDVI (Normalized Difference Vegetation Index) formula to calculate the biomass of vegetation cover through the red and near-infrared spectral bands. Furthermore, multi temporal satellite data can be used effectively to map the changes in the area extent of mangroves. NDVI analysis is a technique that can be applied to vegetation change monitoring which is well established (Galvão et al., 2000; Sader and Winne 1992).

Typical for Halong Bay, there are some major characteristics of mangroves distribution in the area which lead to difficulties in mangrove and wetland detection from satellite images. One issue is that mangroves are distributed gradationally from sparse to dense mangrove forests along the coastline. The heterogeneous landscape in the coastal area made it difficult to accurately separate mangroves from vegetation around settlement areas. Moisture indices helped differentiate mangroves from other vegetation cover types.

Another difficulty with classifying wetland in this area is that the tidal wetland and the coal mining area have similar spectral characteristics with respect to bare land with sparse vegetation. These objects are located at different elevations, so the wetland area could be extracted from coal mining area using a Digital Elevation Model (DEM).

Here, the integrated technique can help to detect wetland habitats. The results from this study provide preliminary information on mangrove changes, and provide support to wetland habitat monitoring. To estimate and control impacts of the development, the rate of mangrove change may be used as an indicator for sustainable development in the coastal area in order to promote coastal zone management for the Halong bay.

1.1 Objectives

This study aims at:

- exploring the use of NDVI imagery for mangrove mapping in the Halong area; studying the distribution of wetland ecosystems in the estuary; usage of remote sensing technology for wetland mapping for Halong Bay area;
- developing a simple technique to display and quantify mangrove forest and coastline changes using different date intervals, results being support for coastal management in the area.

1.2 Area of Study

Study area is the entire coastal area of Halong city and Hoanhbo district (Quangninh province, in the North East of Vietnam). The area is a rectangular zone of which the corner points are defined by the following geographical co-ordinates: 20°54'45"N - 21°55'08"N and 106° 49'53"E - 107°20'30"E. The Halong city has great potential to develop economy in both tourism, industry, and sea transportation. It has been defined by the state as part of the Hanoi - Haiphong - Quangninh economic triangle to be developed in northern Vietnam. Since 1994, after it was recognized as a World Heritage site, the area has been under pressure of development from master plan and economic forces.

The study area includes the Halong bay and Cualuc bay, where the estuary consists of 3 rivers. Research of biologist confirmed that the biodiversity in this area is very rich. This area is selected as a mangrove forest area typical of the North East region of Vietnam (Phan Nguyen Hong, 1994). Mangrove is distributed in a scattered way and varies in extent, which makes it difficult for forest management. Mostly, mangrove is exploited by local population for sea food and fuel wood. Clear cuts of mangroves for shrimp ponds have caused the area of mangrove to significantly decrease.

2. Materials and Methods

2.1 Material

Satellite imagery: Based on the technical approach for multi temporal analysis for change detection of the wetland habitat in the Halong Bay area, the remotely sensed data need to be co-registered. Due to the limitation of available data and budget constraints, three dates of Landsat Thematic Mapper (TM and TM+) imagery were used for the study. Landsat TM has six reflected spectral bands and one thermal band. For vegetation mapping, TM bands number 2, 3, 4, and 5 are particularly useful. The ground resolution is 30 m is adequate for detecting vegetation information in the area of study.

- Three satellite images were acquired: Landsat TM5 image acquired 4 November 1988; acquired from Geo-Informatics and Space Technology Development Agency (GISTDA)Landsat TM5 image acquired 17 February 1998; acquired from GISTDA.

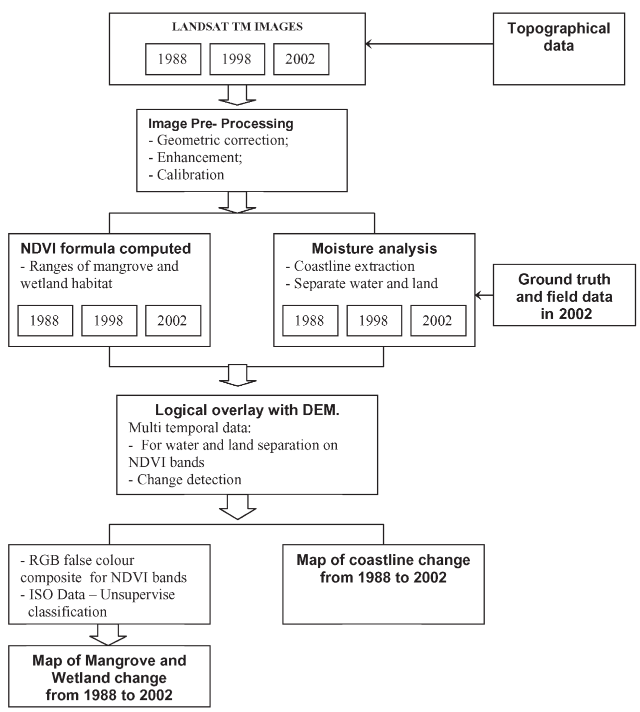

Figure 1: Flow chart explaining the research methodology

- Landsat ETM7+ acquired 31 August 2002; acquired from TRIFIC data centre University of Michigan.

Geographical data. Topographical map at map scale of 1:50000 and 1:10000. Projection: UTM - Zone 48N; Ellipsoid: Everest 1830, Indian 1960. Published in 1997. The co-ordinate system of the baseline data map was used for geometric correction of satellite images, and the elevation contour line was used for create a DEM of the study area. The digital image processing software used for this analysis was PCI 6.2 and Arcview 3.2 is used for GIS analysis and statistic the changing area.

Field trip data: A field trip in April, 2002 was taken to validate the result of the study.

2.2 Methods

A multi-temporal remote-sensing approach was utilized for mapping the mangrove and wetland area in the bay. This methodology is based on the combination of techniques to extract information from remotely sensed data using spectral indices, logical overlay operations, histogram thresholding, and ISODATA clustering.

The research involved these main steps:

- Geometric correction, and pre-processing to enhance image data. Image preparation consisted of geometric rectification to the UTM (WGS 84 datum, zone 48N) coordinate system. The RMS error was less than 10.5m utilizing 10 ground control points for each image.
- The NDVI formula was computed for 3 dates, and values of land cover features including mangrove investigated in the histogram of each NDVI image.
- The Landsat band 5 (Mid-Infrared) and band 4 (Nir-infrared) were used to calculate a soil moisture stress index to detect the wetland habitat. Level slicing was applied for band 4 to detect water area and identify the coastline of the study area. Produce map of coastline change between 1988 and 2002.
- Logical overlay between NDVI images and moisture image and DEM; results of this overlay shows only NDVI values of the wetland habitat and mangrove area.
- The change detection was done by Unsupervised classification with ISODATA clustering method based on the NDVI- RGB false colour composite of three vegetation indices images.

a) Water extraction and soil moisture spectral indices: Water strongly absorbs infrared energy and weakly reflects red light. Thus, the Infrared - Red (IF - R) also has the effect of depicting surface water. Band 4, near-infrared, is useful for delineating water bodies, and further research has demonstrated that band 5 mid-infrared (MIR) is very sensitive to moisture and is therefore used to monitor vegetation water stress and soil moisture. The Moisture Stress Index (MSI) is used for wetland area soil moisture discrimination. This technique was used to separate aquatic, wetland and terrestrial vegetation, Landsat TM band 5 and band 4 are utilized according to this algorithm.

$$MSI = MIR/NIR = TM\ band5 / TM\ band4$$

b) The Normalized Difference Vegetation Index (NDVI) was used to transform multi-spectral data into a single image band repres-

Table 1: NDVI values of the features investigate for different dates

NDVI value / Year	Min	Max	Water body	Tidal wet land	Barren land	Mangrove	Vegetated area
1988	-0.63	0.66	< -0.34	-0.3 ÷ - 0.05	-0.1	0.2 ÷ 0.44	> 0.45
1998	-0.76	0.67	< -0.1	-0.05 ÷ 0.08	-0.21	0.1 ÷ 0.37	> 0.43
2002	-0.66	0.51	< -0.4	-0.19 ÷ 0.3	-0.27	0.05 ÷ 0.16	> 0.23

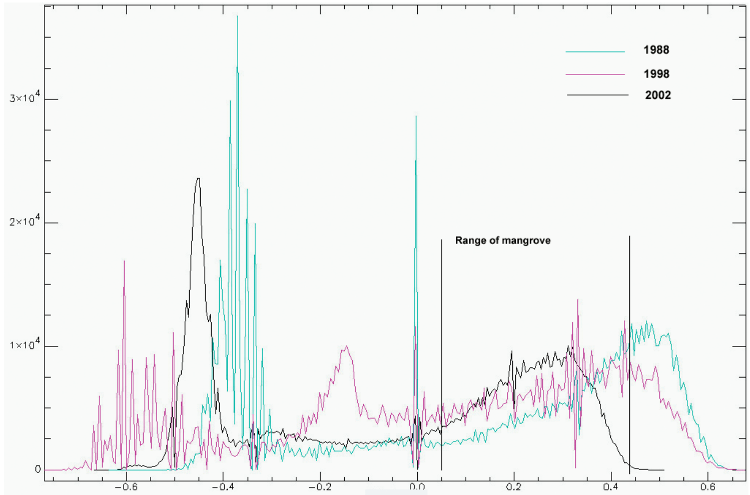

Figure 2: Histogram of 3 bands NDVI (1988 - 1998 - 2002)

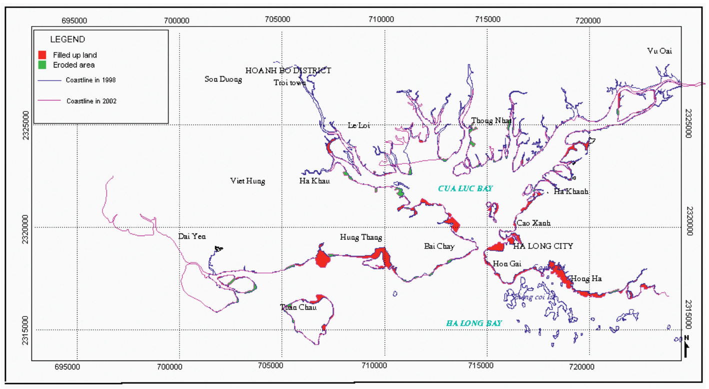

Figure 3: Map of coastline change from 1988 to 2002

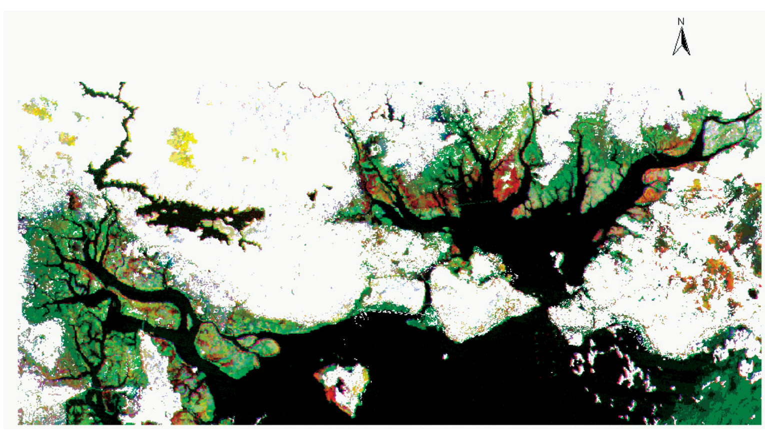

Figure 4: RGB - false color composite of 3 NDVI bands (1988, 1998, 2002).
Display only wetland and mangrove area, the area in dark red show the loss of vegetation (mangrove).

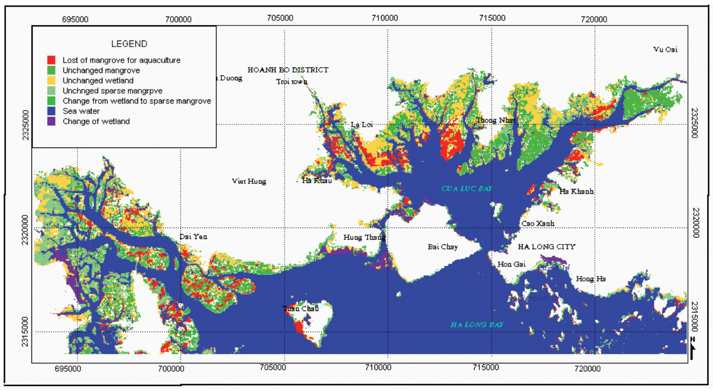

Figure 5: Map of mangrove ecosystem change in the area; result from unsupervised-classification of NDVI false colour composites

enting the vegetation distribution. The NDVI values indicate the amount of green vegetation present in the pixel. Higher NDVI values indicate more green vegetation. NDVI were computed according to the standard algorithm:

$$NDVI = (TM\ band4 - TM\ band3) / (TM\ band4 + TM\ band3)$$

The NDVI equation produces values in the range of -1.0 to 1.0. Areas with green vegetation will have values greater than zero and values near zero or negative values indicate non-vegetated surface features such as water and barren land (reclamation). NDVI values were investigated for 3 dates in combination with the field data. Table 1 and Figure 2 show the values for different type of features which were investigated in the area. The RGB false colour composite of the 3 NDVI images illustrates the change in the coverage of green vegetation between the three dates. This 3 band NDVI composite was used as input applied to the ISODATA unsupervised classification. This produced change classes for mangrove and wetland between 1988 and 2002.

c) Logical overlay operation

- Moisture index values greater than 1 were used as a mask in the NDVI image to separate mangrove from inland vegetation.
- DEM values greater than 2 meters were used as a mask to separate wetland area from coal mining extraction area

Results of this overlay analysis creates an image with only NDVI values in the wetland habitat.

d) ISODATA Clustering: Is an unsupervised classification algorithm that is similar to the K-means (Minimum Distance) procedure, in the sense that cluster centers are iteratively determined sampled means. (Tou Julius, 1974). An advantage of this technique is that it does not require a-priori information (training areas).

The program terminates when the number of iterations reaches maximum number of iterations has been defined, or when the movement of all cluster means is less than movement threshold. For all cluster means, the following situation terminates the program:

$$\frac{\text{New cluster mean position - Old cluster mean position}}{\text{Old cluster mean position}} < \text{Movement threshold}$$

In this case, the NDVI-RGB false colour composite display the change of biomass values in 3 dates, apply the ISODATA clustering to determine the change based on the means, standar deviation of NDVI values and given threshold. The processing was applied for 8 classes, and regroup in to 4 main groups of change in mangrove and wetland, such as: Lost of mangrove; Changed of tidal wetland; Unchanged mangrove; Unchanged tidal wetland area.

Table 2: Area of mangrove and wetland habitat

Wetland and coastal features	area in 1988	area in 1998	area in 2002
Tidal flat	1536.69	1210.87	1345.56
Mangrove area	3029.83	2582.41	2375.15
Aquaculture	0	752.61	852.34
Barren land (Reclamation)	0	141.02	296.24
Total	4566.52	4686.914	4869.29

This methodology is adequate for the change detection of vegetation cover, the classes are automatically separated based on the stasticaly characteristic of NDVI values in each date. The ISODATA unsupervised classification also avoid the subjective idea of the interpreter when determine area of change, and increase system accuracy.

3. Results

Coastline change. As methodology, water bodies were extracted from infrared band of Landsat TM, the level slicing was applied to the values of water reflection for each date. The change of the coastline within 14 years was derived: From 1988 to 2002, along the coastline, about 482.6 ha were used for deposition and reclamation, while 122.05 ha eroded. On the map (Figure 3), the critical area of changes is the Baichay beach and the Cualuc bay. Most of the changes in coastline over time was caused of human activities in development of infrastructure and aquaculture.

Mangrove and wetland habitat change detection: NDVI histograms (Figure 2) showed 3 categories of data sets of 1988, 1998, and 2002. Green vegetation shows highest values in the NDVI histogram curve. Water bodies show negative NDVI values.

Table 1 shows general values of NDVI for each date, and the overall investigation of a feature in the area.

Vegetation values of 2002 present the lowest values compared to 1988 and 1998. The range of vegetated area in 2002 varied from 0.05 to 0.51 which is narrower than other images, this shows that the biomass of the vegetation in 2002 is lower than before (maximum NDVI is value in 1998 = 0.67). The range of tidal wetland in 1998 and 2002 is greater than zero which could explain areas of very sparse vegetation. This was confirmed by field data in 2002, indicating, that mangrove was transformed in tidal wetland and aquaculture. Especially some tidal areas with sparse mangrove are growing.

The logical overlay operation was performed on NDVI and extracted water areas, ensuring that only values of wetland features were present in the histogram. Four features were extracted from the 3 NDVI histograms as follows: tidal flat land, mangrove, aquaculture, and barren land (Table 2). Then, the false colour composite of the 3 NDVI images (RGB-NDVI) was input to the ISODATA unsupervised classification (Figure 4). Change detection was taken as account on the changes that is observed from 1988 to 2002, it illustrates the change within the wetland features. Considering only mangrove areas, the results of the unsupervised classification are 3 groups: no change, loss of mangrove as becoming tidal wetland, and loss of mangrove as changed to aquaculture. Tables 2 shows the statistical relationship of mangrove and wetland habitat calculated for each date.

In general, Table 2 shows that the mangrove area has decreased approximately 654.68 ha and tidal flat land has decreased approximately 191.13ha in 12 years, this both loss area is conversion of mangrove to aquaculture (increase 852 ha) and some area is mangrove degradation become tidal. The tidal flat was filled up to be land for urban area. The total area of wetland habitat has been significantly reduced since 1988. Figure 5 shows the map result of change of mangrove and wetland ecosystem between 1988 and 2002.

4. Conclusions

Several methods can be used to monitor changes in vegetation cover using NDVI classification (Fuller, 1998). Among those techniques, RGB-NDVI classification is the fastest and easiest method to perform (Sedar et al., 2001; Sedar and Winne, 1992). The Vegetation Index techniques for change detection applied in this study show that NDVI values represent well the vegetation distribution as it transformes according to the spectral reflectance characteristics. Mangrove was well distinguished from other vegetation in the study area. Although reflection values of the mangrove and tidal wet land were similar to the coal mining area in the Halong bay, the integrated techniques solved that problem. We applied the integrated remote sensing technique by using band mathematics, NDVI formula and ISODATA clustering for multi temporal analysis. It provided high accuracy classification and detection of features in the coastal area, avoiding the confusion between values and error in classification due to overlap between classes of the training areas (Brook and Kennel, 2002). In this study, NDVI -RGB unsupervise classification were conducted in order to looking the fast and easy method which could provide change information.

The mangrove change detection results for this study area indicate that within 14 years approximately 21% of mangrove cover has been changed in to tidal and aquaculture between 1988 and 2002, and 12% of tidal wetland has been filled up for settlement and industrial zone development. This impact is also present on the change of coastline, that lead to the change of the water level and effect on wetland habitat. The results of this study reflects the strong impact of development activities in the Halong area and effect of the development strategy in recent years, which needs to be corrected and monitor by the provincial authorities. The remote sensing techniques applied in this research provide data for environmental and natural resource inventory and also have shown the driving force of the losing resources; this information may support the coastal zone management plan of the area toward sustainable development.

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