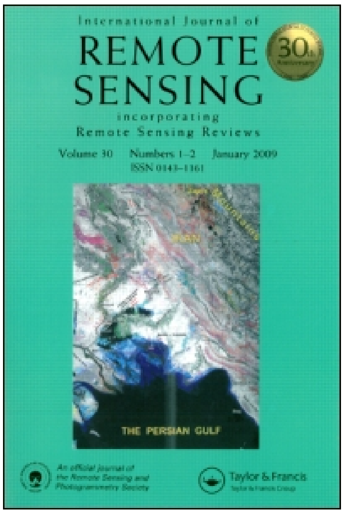

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Land use/land cover changes in the coastal zone of Ban Don Bay, Thailand using Landsat 5 TM data

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Land use/land cover of the Earth is changing dramatically because of human activities and natural disasters. Information about changes is useful for updating land use/land cover maps for planning and management of natural resources. Several methods for land use/land cover change detection using time series Landsat imagery data were employed and discussed. Landsat 5 TM colour composites of 1990, 1993, 1996 and 1999 were employed for locating training samples for supervised classification in the coastal areas of Ban Don Bay, Surat Thani, Thailand. This study illustrated an increasing trend of shrimp farms, forest/mangrove and urban areas with a decreasing trend of agricultural and wasteland areas. Land use changes from one category to others have been clearly represented by the NDVI composite images, which were found suitable for delineating the development of shrimp farms and land use changes in Ban Don Bay.

1. Introduction

Land use and land cover of the Earth is changing dramatically because of human activities and natural disasters. The earth's population continues to suffer the effects of deforestation, flooding, food shortage, green house effect, unplanned urban extension, etc. These environmental problems are often related to land use/land cover changes. It is therefore important to analyse the land use/land cover changes in order to update land use information and develop a sustainable land use plan, which could play an important role for the well being of the global environment.

Land use practices generally develop over a long period of time under different environmental, political, demographic, and socio-economic conditions. These conditions often vary and have a direct impact on land use/land cover. The interaction of nature and society and their implications on land use and land cover is a very complex phenomenon that encompasses a wide range of social and natural processes. Growing human populations exert increasing pressure on the landscape as demands multiply for resources such as food, water, shelter, and fuel. These socioeconomic factors often dictate how land is used regionally as well as locally. To better understand the impact of land use change on terrestrial ecosystems, the factors affecting land use change must be fully examined. Land use and land cover changes have become a central component in current strategies for managing natural resources and monitoring environmental changes. Since the late 1960s, the

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rapid development of the concept of vegetation mapping has lead to increased monitoring of land use and land cover changes worldwide. Providing an accurate assessment of the extent and health of the forest, grassland, aquaculture farms and agricultural resources have become an important priority (Green *et al.* 1994).

Satellite Remote Sensing data, which are a useful source of information and provides timely and complete coverage of any specific area, have proven useful in assessing the natural resources and monitoring the land use or land cover changes (Rantanasermpong *et al.* 1995, Satyanarayana *et al.* 2001). The process of change detection using satellite imagery was employed by utilizing image differencing method (Maus *et al.* 1992, Doak and Lackey 1993, Green *et al*. 1994).

Satellite imagery that could be used for land use changes varies from one study to another. Earlier studies have adopted not only passive sensors like Landsat, SPOT, MODIS, IRS, and NOAA but also Synthetic Aperture Radar imagery. The advantages of multispectral remote sensing to investigate land use changes are availability of reflected radiation from visible and infrared range of the solar spectrum. An additional benefit from satellite images is that these offer the most current information compared to statistics, topographic maps or land use maps. Also, they facilitate retrieval of the information that we need to prepare the record of land use changes in spatial and temporal dimension. This means that the land use categories and information does not necessarily have to comply with any specific nomenclature. Furthermore, satellite images cover large regions and give locations (e.g. where is which land use?). The problems sometimes arise from cloud cover that periodically obscures the surface underneath. The geometric resolution is also limited, but suitable for many practical needs.

Change detection that already is well defined and explained (Singh 1989, Stow 1999, Chavez *et al*. 1995, Deer 1995, Coppin and Bauer 1996, Sader *et al.* 2001) has widespread applications including those of monitoring deforestation, insect inflation, coastal dynamics, shoreline changes and river migration studies. The goal of change detection is to discern those areas on digital images that change features of interest between two or more dates. However, the scientific literatures reveal that digital change detection is a difficult task to perform accurately and unfortunately, many of the studies concerned with comparative evaluation of these applications have not supported their conclusions by quantitative analysis (Singh 1989). Digital change detection is affected by spatial, spectral, temporal, and thematic constraints. The type of method implemented can profoundly affect the qualitative and quantitative estimates of the change. Even in the same environment, different approaches may yield different change maps. The selection of the appropriate method therefore has a considerable significance. Not all detectable changes, however, are equally important to the resource manager. On the other hand, it is also possible that some changes of interest will not be captured very well or at all by any given system.

To date, several change detection methods have been developed using conventional image differencing (consider change in reflection), using image ratio, normalized difference vegetation index, principal component analysis, multi-date image classification, post-classification comparison, manual onscreen digitization (Jensen 1986, Jensen *et al.* 1993, Mas 1997, El-Raey *et al.* 1999). In this study, a series of methods were employed to identify land use changes in the coastal areas of Ban Don Bay, Thailand. The most common approach is digitizing and overlaying to compare the data sets from two dates in order to detect land use changes of the first date data that have been replaced by the new land use in the second date. The second method is image differencing, which simply compares the categories between images. Another method, NDVI differencing, is used to compute different NDVI values between two dates to compare vegetation characteristics; and the last method, NDVI composite (Sader and Winne 1992), is a method that uses three-date NVDI values to detect activities and change or no change during a three-date period.

This paper presents a composite application of several change processing operations of remotely sensed data for change detection to map land use/land cover patterns, as well as identifying changed areas using different time series data of Ban Don Bay, Surat Thani, Thailand over a period of 10 years.

2. Ban Don Bay

Ban Don bay is located between the latitudes 9° 7′ and 9° 25′ N and the longitudes 99° 9′ and 99° 39′ E in Surat Thani province in the southern coastal areas of Thailand (figure 1). The Bay has a total surface area of about 1215 km^2, which encompasses five amphoes (districts): amphoe Tha Chang, amphoe Phun Phin, amphoe Muang, amphoe Kanchanadit and amphoe Don Sak. A linear increase in population from 800,000 to 900,000 during 1993–2001 is observed in this area.

The climate is intermediate between equatorial and tropical monsoon and is characterized by a constant high temperature without extremes of heat, high rainfall with little risk of monsoon failure, and a dry season of moderate severity. During 1996–2000, the rainfall was observed from 900 mm to 2200 mm, the average annual rainfall is 1407 mm. The peak rainfall is in November month, and the driest month is January. The mean annual temperature is 26.8°C. The warmest month is April and the coolest month is December. Two main soil types are the muddy soils developed in the lower part of the tidal range and the acid sulfate or potentially acid sulfate soils in the upper part. Most of the surface freshwater being discharged in Ban Don Bay is from the Tapi-Phum Duang river watershed.

The present land use/land cover patterns in the study area covers mangrove forest/tropical forest, deforest/urban area, agriculture farm, shrimp farm, dry

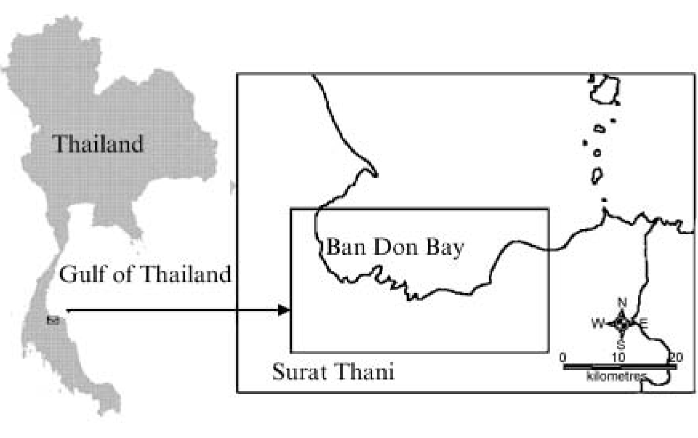

Figure 1. Ban Don Bay, Surat Thani, Thailand.

shrimp farm, planted or replanted shrimp farm and water bodies. Total area of Surat Thani Province is 12,891 km^2. In 1999, accounted agriculture area is 5607 km^2 (43.50%), whereas forest area is 3011 km^2 (23.36%) and other area is 4273 km^2 (33.14%).

According to ONEB-MoSTE (1992), the area of mangrove in Ban Don Bay had been accounted as 4160 ha in 1987. Mangrove forests play an important role in the economics of Ban Don Bay particularly as a source of energy and food protein. Traditionally, the local people have depended on mangrove trees for firewood, charcoal, timber and other minor products. They also depend on mangrove areas for catching fishes, shrimps and crabs. Thailand Development Research Institute (TDRI) (1987) reported a decrease in mangrove area by about 8.5% in Ban Don Bay during 1980–1985, which was faster than an overall decrease of mangroves by 6.5% in Thailand. About 5300 ha of mangrove forest have been converted into shrimp ponds in Ban Don Bay within 10 years (1977–1987), some of the areas were within forest reserves. Poor enforcement of forest laws, a lack of appreciation of the values of mangroves and the incentive of high profits from shrimp farming were the major causes. In Ban Don Bay, mangroves were cleared for firewood, construction materials or charcoal making, aquaculture, tin mining and agriculture. Table 1 represents the major causes of conversion, identifies the affected habitats and the type of regeneration. Data from ONEB-MoSTE (1992) shows that the former mangrove forest now converted into shrimp ponds and agriculture area were 5331 ha and 2727 ha, respectively, in Ban Don Bay. However, often this conversion came from secondary land use changes rather than converting directly into the present land use types.

Aquaculture is a traditional livelihood practice for local people in Ban Don Bay. In the last century, it has expanded rapidly on a commercial basis to meet increased national and international demands. In 1989, about 5000 MT of shrimps were produced.

3. Data used

Landsat 5 Thematic Mapper (TM) data were used in this study. Data acquired were of March 1990, March 1993, January 1996 and January 1999. One visible red band

Table 1. Major causes of mangrove conversion in Ban Don Bay (source: ONEB-MoSTE, 1992).

Major cause of conversion	Habitats most affected	Vegetation that becomes established
Severe cutting of trees for firewood, posts, poles and charcoal-making	Muddy area Sandy loam area Dry soils on inland site with less tidal inundation	Regeneration of young seedlings Regeneration of dense young seedlings Regeneration of dense young seedlings
Agriculture	Mangrove areas at more inland sites	Mangrove forests completely changed into agriculture land, oil palm, rubber and coconut plantations
Aquaculture (shrimp farm)	Most types of mangrove species and habitats	Mangrove forest completely changed into shrimp ponds and after a few years these are left as abandoned shrimp ponds, regeneration of common seedlings of mangrove species

(band 3; 0.63–0.69 μm), a near infrared band (band 4; 0.76–0.90 μm) and a mid-infrared band (band 5; 1.55–1.74 μm) were extracted from original TM data sets because of their vegetation/land cover characterization. Topographic maps from RTSD (Royal Thai Survey Department) at 1:50,000 were used as reference.

4. Methodology

Change detection, which is an important application of remote sensing and has different meanings to different users, invariably involves detection of change—normally its location and extent, and sometimes the identification. The steps for study of land use/ land cover (LU/LC) change detection are shown in figure 2.

4.1 *Geometric corrections*

The Landsat 5 TM images were georeferenced to the digitized map of the corresponding area using first-order polynomial transformation and nearest neighborhood resampling.

4.2 *Supervised classification*

Satellite images were classified to prepare land use/land cover maps of 1990, 1993, 1996 and 1999 (figure 3). The assessment of land use/land cover and changes was performed using GIS. Finally, the recommendations for sustainable coastal land use planning were developed based on the extracted relevant thematic data. Maximum likelihood classifier was employed to generate land use/land cover maps. In order to extract the maximum information on land use/land cover in the study area, classification using the best band combination of Landsat TM imagery was emphasized as the classified images were needed to be used as inputs for change detection analysis.

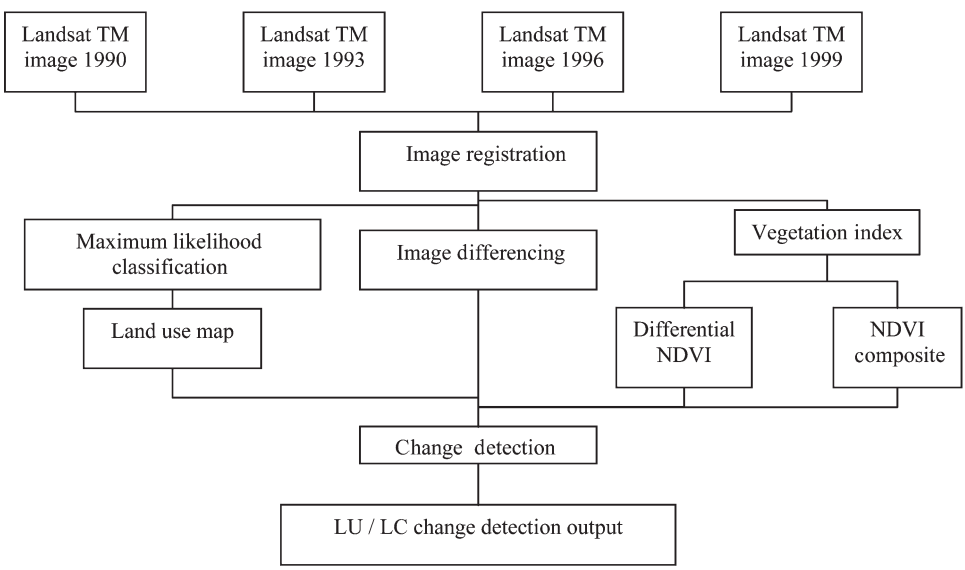

Figure 2. Land use/land cover change detection.

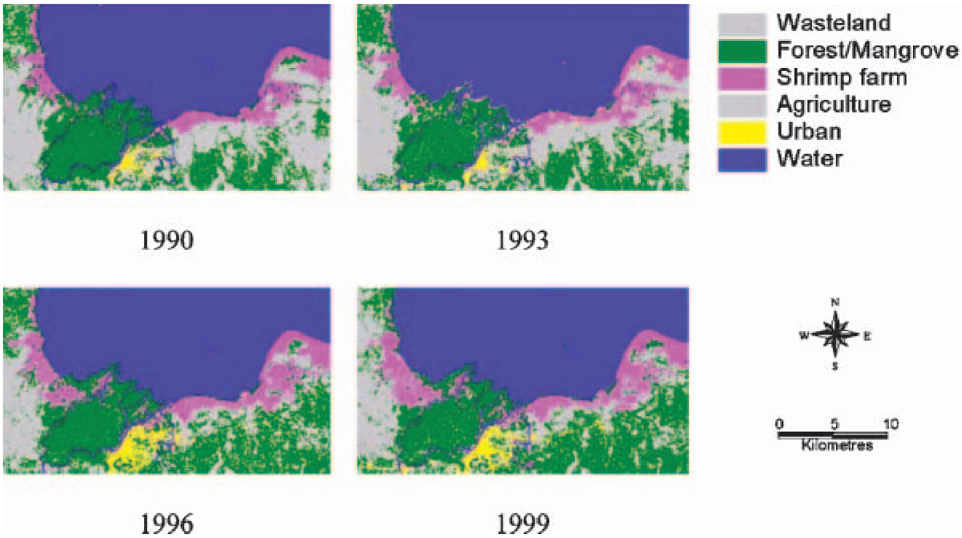

Figure 3. Land cover map of Ban Don Bay.

Conversion of the classified raster images of land use/land cover in vector forms was performed to assess the land use changes during study period.

4.3 *Vegetation indices*

NDVI (Bonfiglio *et al.* 2002, Labus *et al.* 2002) was developed to estimates the green biomass inside study area. The NDVI normally compute the normalized difference of brightness values for data of imagery as shown in equation (1):

$$NDVI = (TM4 - TM3)/(TM4 + TM3) \quad (1)$$

4.4 *Change detection techniques*

Overlaying GIS technique has been used to find the growth that occurred between different time periods. Cross-tabulation has helped determination of which land-use of the earlier date has been replaced by which new land-use. This helps to determine and explain spatial land-use change patterns. The results of change detection using overlaying are shown in figure 4. Important to mention in that a 25 m error could be accepted in digitizing 1:50,000 scale topographic maps.

Image differencing, which appears to perform generally better than other methods of change detection, is probably the most widely applied change detection algorithm for a variety of geographical environments (Singh 1989). It involves subtracting one date of imagery from another date. This method is to compute the differences in digital number or brightness values between two images. Such a monitoring technique based on multispectral satellite data has demonstrated to be a potential means to detect, identify and map changes in forest cover. Four different images 1990–1993, 1993–1996, 1996–1999 and 1990–1999 were created by subtracting the brightness values of later date from those of the previous date (figure 5).

NDVI differencing is the technique to measure biomass change and is a useful tool for mapping the real extent. It is a method to monitor biomass, which compare and

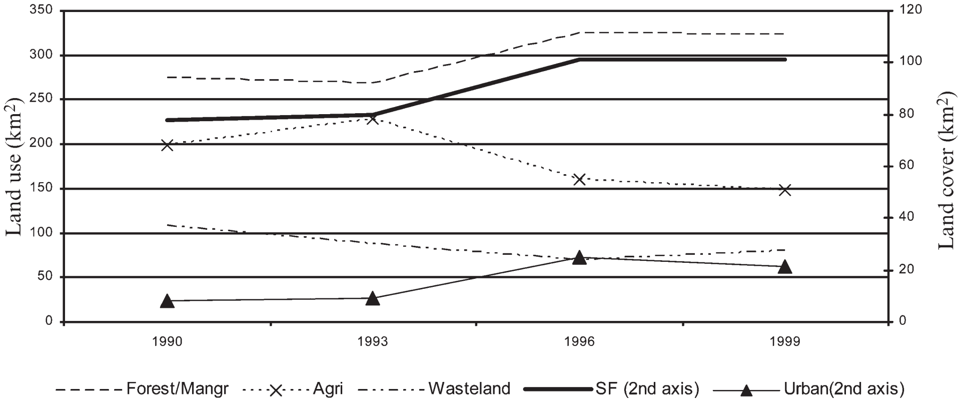

Figure 4. Land use/land cover change in Ban Don Bay during 1990–1999 (km^2).

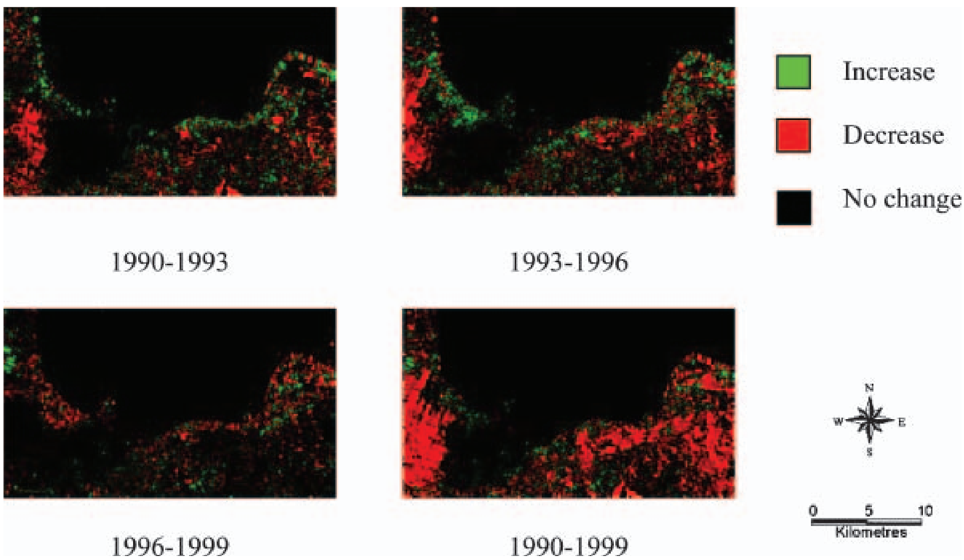

Figure 5. LU/LC change from image differencing techniques during 1990–1999.

compute NDVI values between two date images (figure 6). However, this technique was conducted in areas of dense vegetation/biomass such as mangrove, forest, agriculture area. In order to apply NDVI image differencing individual NDVI image of each date data was developed. Four NDVI difference images were created by subtracting one date of NDVI values from those of the previous date.

Comparison of image differencing and NDVI differencing was also done by overlaying image differencing image and NDVI differencing image to find out the changed area in both methods (figure 7).

NDVI composite classification, the three-date NDVI composite, was developed using an unsupervised clustering routine rather than a threshold technique to classify forest clearing, regrowth and no-change areas between image dates (figure 8). The three-date NDVI composite (1993, 1996, 1999) was clustered based on the distribution of NDVI values over the study area. Clusters representing

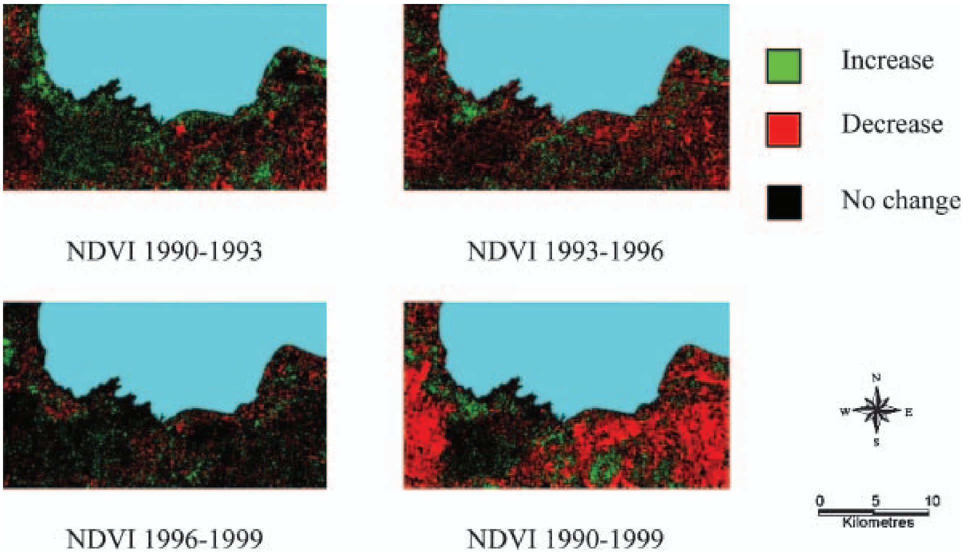

Figure 6. NDVI differencing images during 1990–1999.

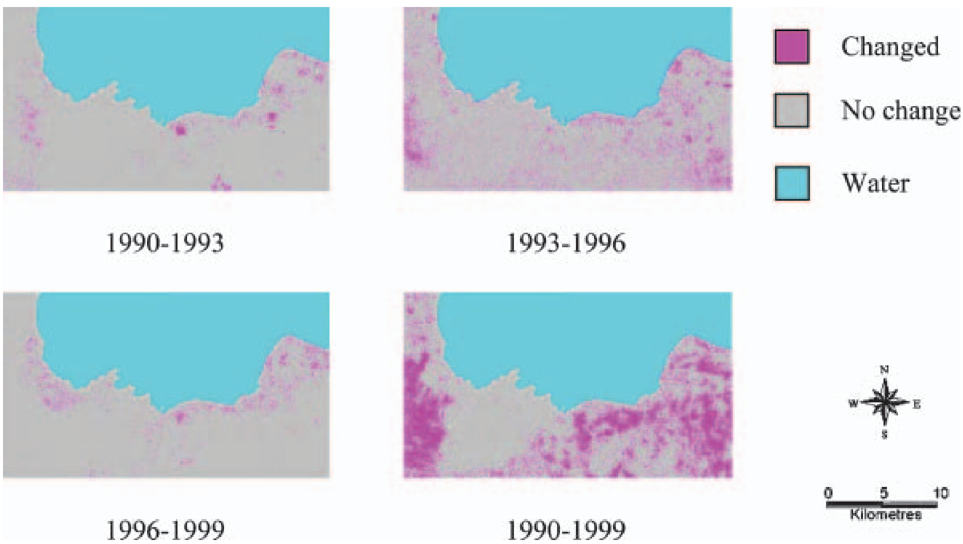

Figure 7. Composite changed areas from image and NDVI differencing techniques.

changes, or showing confusion between known change and no change, were subset from the total cluster set. New clusters were recognized according to the type and time period of change. Using the cluster signature statistics and additive colour theory, interpretation of the raw NDVI composite image was made. This image was then recombined with the no-change forest class from the first iteration to produce the final NDVI composite change-detection classification by using K-mean classifier, unsupervised classification (Tou and Gonzalez 1974).

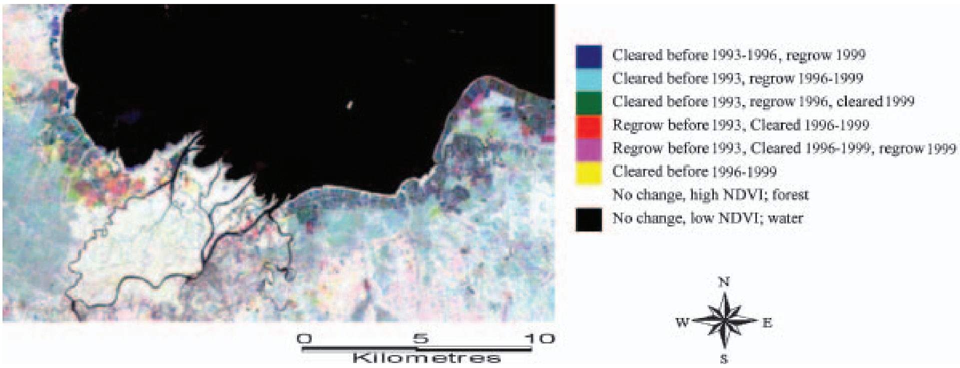

Figure 8. NDVI composite image from 1993, 1996, 1999.

4.5 *Post classification*

Post classification is carried out to improve the classified images to evaluate classification accuracy and to generalize classes to use in vector GIS.

5. Problems, limitations and accuracy of the study

One difficulty encountered in employing image differencing change-detection was the selection of the appropriate threshold values in the histogram that separates real and false change. But this subjectivity of threshold placement can be improved by the analyst's familiarity with the study area as well as access to ancillary data such as field information, GIS data, and/or matching dates of aerial photography. Tested quantitative methods for developing these threshold levels using accuracy indices, the *Kappa* coefficient in determining an optimal threshold level, are being based on an error matrix of image data against known reference data. The classification accuracy was 95–97% with 0.90–0.95 *Kappa* coefficient index.

6. Results and discussion

The major outputs of this study are the compilation of relevant thematic databases, assessment of land use/land cover distribution in 1990, 1993, 1996, and 1999 as well as dynamics or changes in land use and land cover during 1990–1999.

6.1 *Assessment of land use/land cover*

The land use and land cover categories in 1990, 1993, 1996 and 1999 were extracted by visual interpretation of satellite image at a scale of 1:50,000. The categories are (1) shrimp farm, (2) mangrove and forest, (3) agriculture, (4) wasteland, (5) urban and (6) water. Figure 3 shows the land use/land cover classified map of 1990, 1993, 1996 and 1999.

The final classified maps of 1990 and 1999 were overlaid using a different method to generate a land use/land cover change map of the coastal areas of Ban Don Bay. The area under different land-use classes in 1990, 1993, 1996 and 1999 are presented in figure 4. During 1993–1999, an increasing trend for shrimp farming activities, forest/mangrove and urban was observed while a decreasing trend was observed for agriculture. For wasteland, the trend was decreasing during 1990–1996 and thereafter increasing until 1999. A clear reforestation or afforestation is also apparent in the study area. While assessing the changes in new shrimp farm area although turbid water could not be separated from shrimp ponds, the distinguishing was feasible in post classification image using shape feature and location information.

Four different images were created using image differencing technique by subtracting digital numbers of one date from those of the previous date (figure 5). A clear observation of these resultant images show that much of the changes have occurred during 1990–1993 and 1993–1996 whereas the change is minor in 1996–1999. However, in the upper left portion, the observed increase during 1990–1993 and 1993–1996 was nullified by a decrease in 1996–1999 and the resultant nil change in seen in change image for 1990–1999.

Four difference images were created by subtracting one date of NDVI values from those of the previous date (figure 6). The results of 1993–1996 land use/land cover changes obtained from image differencing (figure 5) and NDVI differencing (figure 6) have yielded very similar results—10.84 and 10.89, respectively. The images show closer results of land use changes like image differencing technique. Observations on increasing and decreasing trends of different land use classes using NDVI values are shown in red, which shows changes from forest/mangrove to shrimp farm (15.2%) and from wasteland to shrimp farm (16%). Green depicts changes from wasteland to agriculture (15.5%) and agriculture area to forest area (15.9%). However, the maps created from image differencing (figure 6) and NDVI (figure 5) differencing clearly shows that major change has occurred during 1993–1996. Figure 7 represents the composite changed area derived by *overlay technique* from both NDVI differencing method and image differencing. Results are almost similar with less than 12% variation than other two methods presented in figures 5 and 6.

NDVI composite classifications (NDVI values from 1993, 1996 and 1999) were categorized as very high, high, medium-high, medium, medium-low, low and very low based on the distribution of NDVI values over the study area. Each cluster was further examined for changes in NDVI levels. An unsupervised classification map was created to show the type of changes, as shown in figure 9. Several vegetation classes such as mangroves, evergreen forest and mixed plantations are merged as the vegetation class. Although the study area, situated

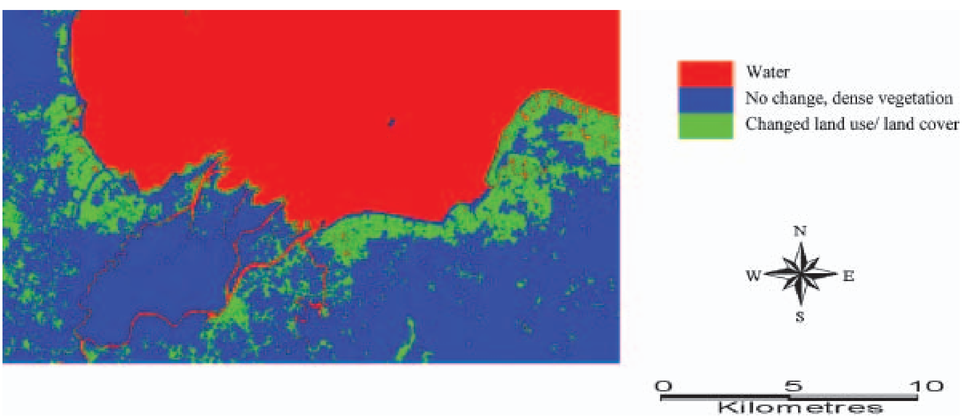

Figure 9. Unsupervised classification of NDVI composite image.

Table 2. Field check in 2002.

Sample Site	TM 1990	TM 1999	Field check in 2002	Confirmed
1	Agriculture	Shrimp farm	Shrimp farm	Yes
2	Mangrove	Shrimp farm	Shrimp farm	Yes
3	Shrimp farm	Mangrove	Mangrove	Yes
4	Mangrove	Shrimp farm	Lime stone	
5	Mangrove	Shrimp farm	Shrimp farm	Yes
6	Mangrove	Shrimp farm	Shrimp farm	Yes
7	Mangrove	Shrimp farm	Shrimp farm	Yes
8	Shrimp farm	Mangrove	Mangrove	Yes
9	Agriculture	Shrimp farm	Shrimp farm	Yes
10	Clearing land	Forest	Forest	Yes
11	Forest	Wasteland	Wasteland	Yes
12	Wasteland	Shrimp farm	Shrimp farm	Yes
13	Wasteland	Shrimp farm	Shrimp farm	Yes
14	Wasteland	Shrimp farm	Shrimp farm	Yes
15	Forest	Shrimp farm	Shrimp farm	Yes
16	Mountain	Mountain	Mountain	Yes
17	Wasteland	Forest	Forest	Yes

at coastal zone, regularly experiences the monsoon the temperature variation is low and the weather is not much different during wet and dry or warm and cool season. The forest in the area is evergreen forest. As a result, the NDVI results do not show any significant difference. Hence the study could exclude the seasonal phenology of the area and is focused only on change detection from one land use to another, such as vegetation to shrimp farm, agriculture to shrimp farm, etc.

6.2 *Field verification of LU/LC changed*

A field check or accuracy test was conducted in November 2002 on random sample sites. Seventeen random sites were selected to cover variety of changes that took place in the study area (table 2). Sixteen interpretations of changes from this study were found to be correct. Only one error was found in predicted result. Site 4 was predicted to be an area that had been changed from mangrove to dry shrimp farm but during the field verification it appeared as an area with limestone storage yard.

7. Conclusions

The remote and inaccessible nature of many tropical forest and the rapid changes in land use/land cover make remote sensing techniques an essential tool to monitor the landscape and generate valuable data, which can be interpreted by various technique and methods. Multi-temporal and multi-spectral data from Landsat 5 TM after image analysis successfully delineated the land use/land cover changes in Ban Don Bay, Surat Thani, Thailand. Most of the changes were observed in the wastelands, shrimp farms, and vegetation. From the field visit it was found that several changes are due to the development of plantations: rubber and coconut. It was also found that the majority of the changes have occurred during 1993–1996 when compared to 1990–1993 and 1996–1999. Local people developed shrimp farms on a large scale during 1994 by converting available wasteland, and vegetation around coastal areas because of its commercial value. Because of strict Thai regulation, mangrove and forest was not allowed to cut, and it also grew. An increase in the forest, mangrove, urban and shrimp farms was observed in figure 4. This increase is at the expense of a decrease in the wastelands and agricultural area. Generally shrimp farms adversely affect the mangroves, but thanks to strict Thai regulations mangrove cover has increased.

Changes observed in figures 6 and 7 are obtained using NDVI. Results from this approach also indicate an increasing trend in mangrove coverage. The NDVI differencing approach mostly highlights changes from vegetation to other land use or from other land use to vegetation. Land use changes from one category to another are shown clearly in the NDVI composite image in figure 8. K-mean classification of the NDVI composite image was found useful for delineating the development of shrimp farms in the bay (figure 9). The methods employed in the study and Landsat data were useful to investigate the land use change pattern in the Ban Don Bay, but the results would have presented more details if high spatial resolution data were utilized. Remote Sensing demonstrated the potential for monitoring the land use resources. Monitoring and planning of land use in coastal zones can be effectively carried out by integrating and analysing the output raster maps in GIS.

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