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Land Cover Mapping and Change Detection Analysis over Nanggroe Aceh (NAD) Province after Tsunami

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1. Introduction

Land cover as the basic parameter to evaluate the content of Earth surface, are important factors that affect ecosystem condition and function (Lunetta et al., 2006). In addition, it is also as a biophysical state of the Earth, which can be used to estimate the interaction in form of biodiversity, biosphere-atmospheric and geosphere-atmospheric interactions. Hence, land cover analysis plays an important role in many environmental applications nowadays. There has been growing interest in the use of remote sensing systems for a regular monitoring of the Earth's surface. The availability of remote sensing data applicable for global, regional and local environment monitoring has greatly increased over recent years (Ehlers et al., 2003). Availability of accurate and up-to-date land cover information is central to much resource management, planning and monitoring program (Kasetkasem at al., 2005). Remote sensing is an attractive source to produce thematic maps such as those depicting land cover as it provides a map-like representation of the Earth's surface that is spatially continuous, as well as available at a range of spatial and temporal scales. Thematic mapping from remotely sensed data is typically based on an image classification (Foody, 2002). Satellite remote sensing methods, which can in principle, be used to monitor very large areas in a reasonably short period of time, have notable potential for monitoring this high-latitude vegetation, although the techniques are in general less well established than at lower latitudes (Rees et al., 2003). Information on land-cover status at the regional scale is needed for natural resource management, carbon cycle studies, and modeling of biogeochemistry, hydrology, and climate. Satellite-based remote sensing products can meet these data needs in a timely and consistent manner (Boles, et al., 2004). Besides that, change detection analysis becomes extremely important in order to understand the interactions and relationships between natural phenomena and human, through the accurately change detection of Earth's surface features (Lu et al, 2003). Usually, change detection analysis involved utilization of multi-temporal satellite images to determine the temporal effects for every phenomenon in quantitatively. One of the aspect of change detection applications using remote sensing technique, such as land-use and land-cover changes. Many researchers used remotely sensed images in their land use and land-cover studies (Friedl et al., 2002). This is due to multi-temporal maps of land-use and land-cover changes are useful in identifying temporal changes, which have implications for local, regional or global environmental changes. Furthermore, abrupt changes in surface content may be due to the natural environment or anthropogenic activities (Fernandes et al, 2004). All of these may be interrelated. From the study done on Nanggroe Aceh Darussalam (NAD), the study focuses on the land-cover mapping and change detection analysis to identify the coastal change before and after the Tsunami effect. Using remote sensing data to detect coastal line change requires high spatial resolution data. In this study, two high spatial data with 30 meter resolution of Landsat TM images captured before and after the Tsunami event were acquired for this purpose. The two satellite images was overlain and compared with pre-Tsunami imagery and with after Tsunami. The two Landsat TM images also were used to generate land cover classification maps for the 24 December 2004 and 27 March 2005, before and after the Tsunami event respectively. The standard supervised classifier was performed to the satellite images such as the Maximum Likelihood, Minimum Distance-to-Mean and Parallelepiped. High overall accuracy (>80%) and Kappa coefficient (>0.80) was achieved by the Maximum Likelihood classifier in this study. Estimation of the damage areas between the two dated was estimated from the different between the two classified land-cover maps. Visible damage could be seen in either before and after image pair. The visible damage land areas were determined and draw out using the polygon tool included in the PCI Geomatica image processing software. The final set of polygons containing the major changes in the coastal line. An overview of the coastal line changes using Landsat TM images is also presented in this study. This study provided useful information that helps local decision makers make better plan and land management choices.

2. Change detection analysis

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different time (Singh, 1989). Processing of multi-temporal images and change detection techniques has been developed in the past three decades. Change information of the Earth's surface is becoming more and more important in monitoring the local, regional and global environment. There are a lot of successful studies found from many research in application cases, especially on the detecting and monitoring environmental change.

The remote sensing imagery from previously till presently can provide valuable data through timely and accurate change detection of Earth's surface features, by providing the basic for better understanding the relationships between human and natural phenomena to better manage and use resources (Lu et al., 2003). Basically, the different algorithms can be grouped into the following categories: algebra (differencing, rationing, and regression), change vector analysis, transformation (e.g. principal component analysis, multivariate alteration detection, Chi-square transformation), classification (post-classification comparison, unsupervised change detection, expectation-maximization algorithm) and hybrid methods. Since monitoring change of Earth's surface features is very important, research of change detection techniques is an active topic, and new techniques are steadily developed.

The purpose of conducting change detection is to compare spatial representation of two points in time by measuring changes caused by differences in the variables of interest and controlling all variables caused by differences in variables that are not of interest (Green et al., 1994). Normally, change detection involves the utilization of multi-temporal satellite imagery to quantitatively analyze the temporal effects of the phenomenon. Therefore, the available remotely sensed data, such as radar, Advanced Very High Resolution Radiometer (AVHRR), Thematic Mapper (TM), and Satellite Probatoire d'Observation de la Terre (SPOT), play an important role for different change detection applications. Ten aspects of change detection applications using remote sensing technologies are summarized:

1. Land use and land cover (LULC) change (Lunetta et al., 2002; Read and Lam, 2002; Weng, 2002)
2. forest or vegetation change (Woodcock et al., 2001; Lu et al., 2002)
3. forest mortality, defoliation and damage assessment (Rigina et al., 1999)
4. deforestation, regeneration and selective logging (Asner et al., 2002; Wilson and Sader, 2002)
5. wetland change (Munyati, 2000)
6. forest fire (Bourgeau-Chavez et al., 2002)
7. landscape change (Taylor et al., 2000)
8. urban change (Zhang et al., 2002)
9. environmental change (Kimura and Yamaguchi, 2000)
10. other application such as crop monitoring (Engeset et al., 2002)

A good and successful change detection research should provide the following information: (1) accuracy assessment of change detection results; (2) area change and change rate; (3) spatial distribution of changed types; and (4) change trajectories of land cover types (Lu et al., 2003). In addition, there are four major steps are involved when implementing a change detection analysis: (1) precise radiometric and atmospheric calibration or normalization between multi-temporal images; (2) precise registration of multi-temporal images; (3) selection of the same spatial and spectral resolution images if possible; and (4) similar phonological states between multi-temporal images.

One important area where remote sensing plays a key role in change detection analysis is the study of land cover change. The study on land cover change is an important finding in the Earth Science domain because of its impacts on local climate, biogeochemistry, hydrology, radiation balance, and the diversity and abundance of terrestrial species (Mas, 1999). Definitely, the conversion of natural land cover types to human-induced cover types continues to be a change and bring an environmental problem for local, regional or global scales (Weng, 2002). The land cover change detection problem is essentially one of the detecting when the land cover at a given location has been converted from one type to another.

3. Land cover mapping

The main purpose of land cover mapping is to serve as a main reserve of land resources in local, regional or global levels in the world for all levels of environmental agencies, government, and private industry. Remote sensing technique provides valuable land cover data for local or regional level, from the past history till recently. Land cover composition and change are important manners for many scientific research and socioeconomic assessments (Xian et al., 2009). Information regarding the land cover types and distributions can be utilized to monitor the status of ecosystems change over desired period and assess landscape condition (Coppin et al., 2004). Continuous monitoring of the types and locations of LULC change gives us an obvious view on change mechanisms and to model impacts on the environment and associated ecosystems (Homer et al., 2004; Xian and Crane, 2005). Many studies have been

done on the regional land cover mapping and it can be used as a guideline for future monitoring and land management by policy-makers or local authorities in order to avoid any environmental change caused by improper planning in LULC (Kumar et al., 2009).
Usually, the process of land covers mapping involved image classification. The aim of classification analysis is to categorize all the pixels in the digital satellite imageries into land-cover classes. Basically, the process can be divided into three simple steps, the pre-processing step, data classification and output. For the first step of pre-processing, the digital satellite images were chosen for land-cover mapping. For the second step of data classification, the digital satellite images were processed using PCI Geomatica image processing software. Supervised classifications operate in three basic steps: training, classification, and accuracy assessment. Training sites are needed for supervised classification. The areas were established using polygons. They are delineated by spectrally homogenous sub areas, which have, class name given. The satellite images were the classified using the three supervised classification methods (Maximum Likelihood, Minimum Distance-to-Mean and Parallelepiped).

4. Study area

The Landsat TM imageries used in this study were acquired on 24 December 2004 and 27 March 2005. The selected study area was Nanggroe Aceh Darussalam (NAD) province, Indonesia. Figure 1 shows the study area. The study area is in the Sumatra Peninsula, located between latitudes 2ºN and 6ºN and longitudes 95ºE and 99ºE (Figure 1), at the nortern tip of the island of Sumatra. NAD province is located in equatorial region and enjoys a warm equatorial weather the whole year. Therefore, it is impossible to get the 100 % cloud free satellite image over NAD province. But, the satellite image chosen is less than 10 % cloud coverage over the study area.

Fig. 1. The study area of NAD province, Indonesia.

There are five main islands (Sumatra, Java, Kalimantan, Sulawesi, and Irian Jaya) in Indonesia. Indonesia covers total land area for approximately 1919317 km² (Banda Aceh-Wikipedia, 2010). While NAD province covers an area of 57365 km2. Total population in NAD province is about 3930000, with the major ethic of acehnese. It is western most province of the Indonesia with Indian Ocean to the west, the strait of Malacca to the east. Bukit Barisan mountain ranges with tangse, gayo and Alas upland is located in the central part of this province. The highest peaks are Leuser (3466 m), Ucop Molu (3187 m), Abong – abong (3015 m), Peut Sago (2786 m), and Geureudong (2295 m) and Burni Telong (2566 m).

The main variables of NAD province's climate are rainfall, rather than air pressure or temperature, with the weather of tropical, hot and humid throughout the year. NAD province has a dry and wet season. The dry season is from March through to August and the wet season from September to February. The average annual rainfall ranges from 2000 mm to 3000 mm, with tempearature ranging from 25 to 30° Celsius. The mean daily humidity varies between 65 % to 75 %.

5. Satellite remote sensing data

The research has been carried out in USM with the utilization of satellite images from passive sensors in our analysed. Images acquired by Landsat TM 5. Landsat 5 was launched by NASA on March 1 1985 in order to replace Landsat 4. Landsat 5 was designed and built at the same time as Landsat 4 and carried out the same payload: the Multispectral Scanner System (MSS) and the Thematic Mapper (TM) instruments.

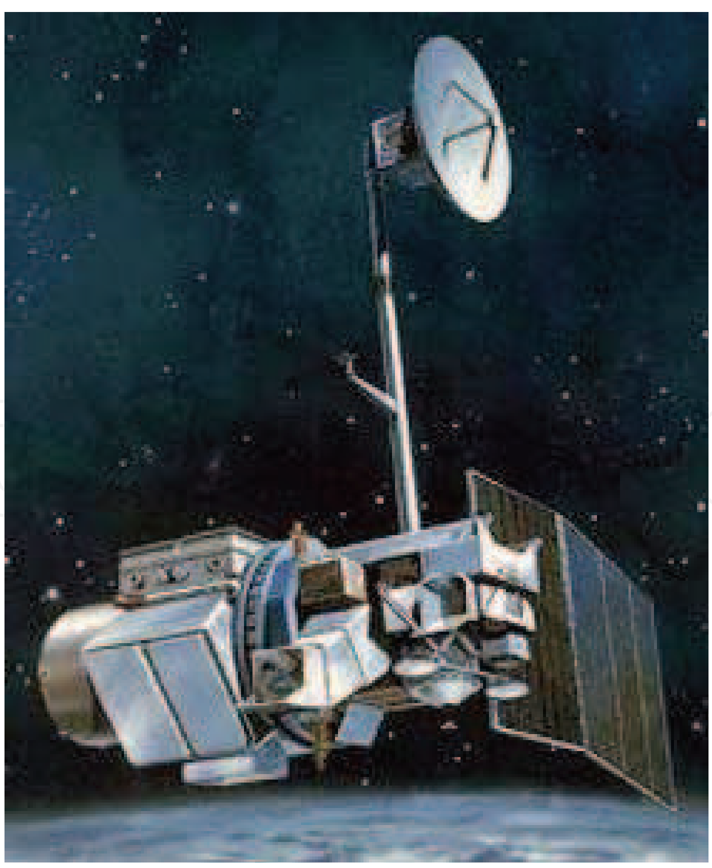

Fig. 5. Landsat Satellite TM.

6. Data analysis and results

On 26 December 2004 an underwater earthquake, measured at 9.0 on the Moment Magnitude scale, occurred off the coast of NAD on the island of Sumatra, in the Indonesian Archipelago. The resulting tsunamis have killed tens of thousands, with many more people missing, feared to be washed out to sea and drowned. Areas near to the epicentre in Indonesia, especially Banda Aceh, were devastated by the earthquake and tsunami.
The final death toll, taking into account missing persons, is likely to exceed 100,000 with up to two million people displaced and made homeless. The effects of the tsunami were also strongly felt in the coastal regions of Thailand, Malaysia, Myanmar (Burma) (UNICEF report), Sri Lanka (UNICEF report), India (UNICEF report), Maldives, and as far away as the coasts of Africa.
Many town areas were destroyed or devastated. The Indian Ocean tsunami was one of the greatest tragedies of recent history. The toll in deaths, injuries and human suffering was enormous. Whole communities were destroyed and displaced. Damage to property, infrastructure and the environment was also immense. In parts of South East Asia and Africa the tsunami caused many deaths yet left no lasting scar on the landscape. Elsewhere towns were devastated, entire villages destroyed and wide swaths of agriculture, forest and grazing- land washed away.
A full TM scene (path 131, row 56) recorded on 24 December 2004 was used as a reference image before the Tsunami event. The 27 March 2005 was the only cloud free image recorded after the Tsunami event. Figure 2 shows the raw satellite images for 24 December 2004 and 27 March 2005. All image-processing analysis was carried out using PCI Geomatica version 9.1.8 software at the School of Physics, University of Science Malaysia (USM). Figure 3 shows the coastal line change map over Indonesia. The white line on the figure depicts the original coastline, the red represents the post-tsunami situation.
From the two images displayed, we can clearly see that the area near the coastal line on 27 March 2005, viz after the Tsunami, was previously vegetated on 24 December 2004, viz before the Tsunami. The distributions of seriously damaged land cover along coastal line of the North West Sumatra, Banda Aceh is shown in Figure 3.
Land cover classification was accomplished in three steps. The first step in pre-processing was to apply a brightness correction technique to the digital images. The second step was to classify all the pixels in the digital images into land cover classes. Training sites were needed for supervised classification. A total of 45 training sample areas were established in this study. The digital image was classified into five classes using all three visible bands and three infrared bands (water, urban, vegetation, cloud, unprocessed area). The final step is the accuracy assessment. The available ground truth data were used to derive an accuracy assessment analysis for the classified map. The overall accuracy is expressed as a percentage of the test-pixels successfully assigned to the correct classes. The high Kappa coefficient suggests a good relationship between the classified image and the reference data. A total of 200 samples were chosen randomly for the accuracy assessment in this study. The assessment results showed a reasonably good agreement between the land cover data set and the reference data. The produced results in this study are shown in Table 1. The accuracy assessment results are shown in Table 2 and 3. Finally, the land cover damaged areas were calculated from two classified maps. Table 4 shows the area of LULC changes in

NAD province, which was generated based on the data acquired from image classification. From this table, all the land cover types have been compared within the area covered by them, in 24 December 2004 and 27 March 2005, before and after Tsunami event.

(a)

(b)

Fig. 2. Raw satellite images used in this study, (a) 24 December 2004 (b) 27 March 2005.

(a)

(b)

Fig. 3. Illustration of the original coastline and the post-tsunami situation, a) 24th December 2004 b) 27th March 2005

Classes	24 December 2004	27 March 2005
Water	20768.1921	17302.0662
Urban	4035.3732	3525.2577
Vegetation	8798.6754	8692.7544
Cloud	1996.1550	2099.3643
Unprocessed Area	6449.6925	10428.6456
Total	42048.0882	42048.0882

Table 1. Statistic analysis for the areas (in km).

Classification method	Kappa coefficient	
	24 December 2004	27 March 2005
Maximum Likelihood	0.8125	0.8236
Minimum Distance-to-Mean	0.6525	0.6895
Parallelepiped	0.4258	0.4582

Table 2. The Kappa coefficient for the two images.

Classification method	Overall classification accuracy (%)	
	24 December 2004	27 March 2005
Maximum Likelihood	89.25	91.25
Minimum Distance-to-Mean	72.21	78.06
Parallelepiped	55.36	59.36

Table 3. The overall classification accuracy for the two images.

Classes	Area changes from 24 December 2004 to 27 March 2005 (km^2)	Percentage (%)
Water	-3466.1259	-16.6895
Urban	-510.1155	-12.6411
Vegetation	-105.921	-1.2038

Table 4. Results of land use classification for 24 December 2004 and 27 March 2005 images showing the area changes of each class.

Accuracy assessment of coarse-resolution land cover products is a critical and challenging task, as these maps can overestimate or underestimate cover types due to the fragmentation and sub-pixel proportion of each cover type. As an alternative approach to field surveys, fine-resolution images and derived land cover maps have been used for validation of coarse-resolution thematic maps. In this study, validation was performed using the in situ data collected during the fieldwork in the study area. The classified land cover maps using Maximum Likelihood Classifier are shown in Figures 4 and 5 for 24 December 2004 and 27 March 2005 respectively.

7. Conclusion

This study indicated that the digital satellite imagery could provide useful information for remotely sensed data. The Maximum Likelihood classifier classification method proved to be very efficient to classify land cover over Nanggroe Aceh Darussalam (NAD) province, Indonesia. An overall accuracy and overall Kappa higher than 80 % were achieved using Landsat TM image. This land cover map was very useful for urban planner especially after the Tsunami event that occurs on the 26 December 2004. Recent satellite based instrument and digital image-processing techniques now make the coastal line changes over a big coverage of study area possible. Further studies have to be carried out to investigate the coastal line features and their spatial relationship relative to the physical land–water boundary.

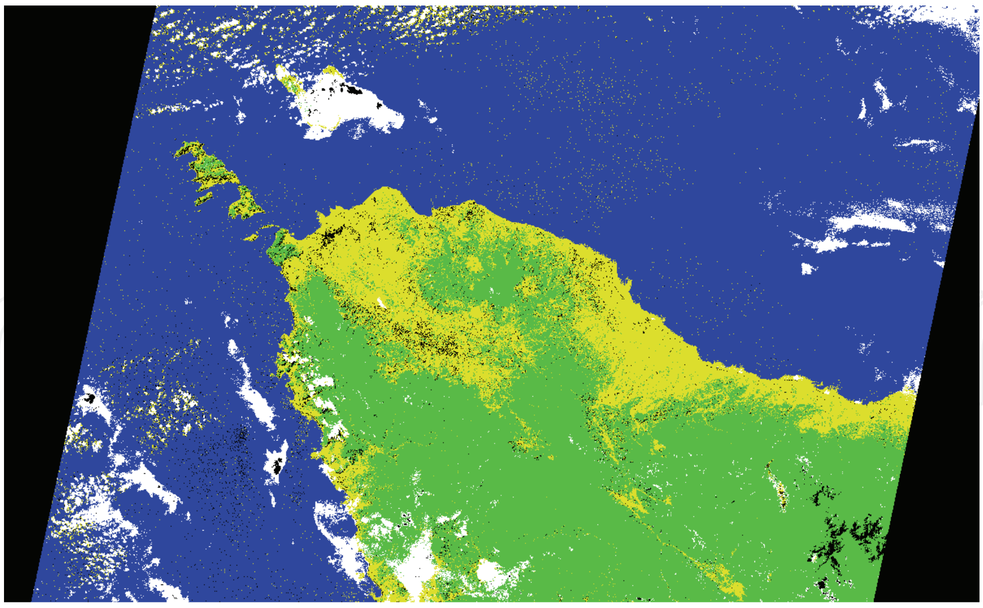

Fig. 4. The land cover map using Landsat TM image (24 December 2004) [Color Code: Green = vegetation, Yellow = land/urban, blue = water, White =cloud and Black = Unprocessed area]

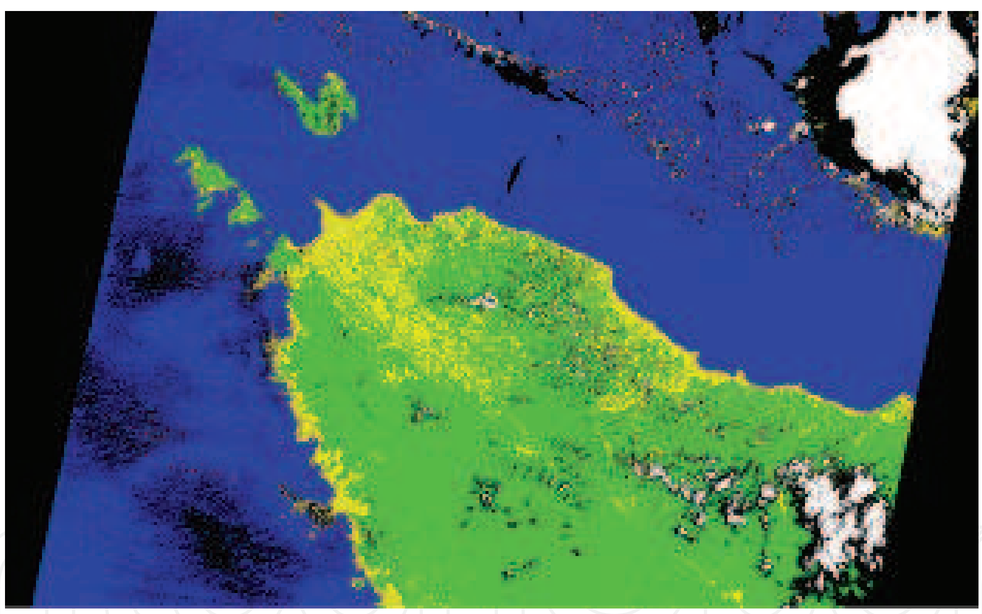

Fig. 5. The land cover map using Landsat TM image (27 March 2005) [Color Code: Green = vegetation, Yellow = land/urban, blue = water, White =cloud and Black = Unprocessed area].

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Submarine earthquakes, submarine slides and impacts may set large water volumes in motion characterized by very long wavelengths and a very high speed of lateral displacement, when reaching shallower water the wave breaks in over land - often with disastrous effects. This natural phenomenon is known as a tsunami event. By December 26, 2004, an event in the Indian Ocean, this word suddenly became known to the public. The effects were indeed disastrous and 227,898 people were killed. Tsunami events are a natural part of the Earth's geophysical system. There have been numerous events in the past and they will continue to be a threat to humanity; even more so today, when the coastal zone is occupied by so much more human activity and many more people. Therefore, tsunamis pose a very serious threat to humanity. The only way for us to face this threat is by increased knowledge so that we can meet future events by efficient warning systems and aid organizations. This book offers extensive and new information on tsunamis; their origin, history, effects, monitoring, hazards assessment and proposed handling with respect to precaution. Only through knowledge do we know how to behave in a wise manner. This book should be a well of tsunami knowledge for a long time, we hope.