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Detecting land cover change in Hambantota district, Sri Lanka, using remote sensing & GIS.

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A Minor Field Study

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Abstract

The location for this study has been Hambantota district in Sri Lanka. The main aim in the study was to develop a methodology to detect land cover changes in the study area with focus on agricultural areas. Questions asked were if there was any agricultural areas abandoned or if a crop diversification process had taken place. A second aims was to investigate possible changes to the land cover as an affect of the Tsunami in December 2004. The tools to help answer these questions were GIS and remote sensing with satellite data from the Landsat program. The method approach chosen was a combination of different techniques put into a knowledge based classification algorithm, together with information from interviews and field data collected during the field visit in Sri Lanka. The combination of these different methods and data sources served as a good instrument locating land cover changes.
The results showed that an increase in rural housing areas had taken place between the late eighties early nineties. There had also been a small increase in agricultural lands in the region. In many areas the agricultural crop dynamic has changed as well. Farmers have started growing bananas instead of the traditional paddy rice. The major explanation is the larger revenues that banana gives but also that there have been a water shortage so the farmers have changed to the less water demanded banana plant.

Keywords: Physical Geography, Geography, Land cover change, GIS, remote sensing, Sri Lanka

Sammanfattning

Målet med denna studie är att undersöka landskapsförändringar i Hambantota distriktet i Sri Lanka och att komma fram med en lämplig metod för att utföra detta. Delmål var bland annat att besvara om jordbruksmark i området har övergivits eller om grödorna som bönderna odlar har bytts ut eller blivit fler. I december 2004 drabbades Sri Lanka av en Tsunami som kostade många människors liv och materiell förstörelse. Ett mål för studien var även att undersöka om Tsunamin hade påverkat markanvändningen, framförallt jordbruksmark i distriktet. För att kunna besvara frågorna och nå målen har GIS, fjärranalys och fältdata använts och analyserats. Under en resa till Hambantota distriktet har fältdata samlats in, fältresan betydde även mycket för att få en klar bild över området och för att förstå problemställningen. Metoden som utvecklats använder sig av flera informationskällor och sammanför dessa för att få ett så pålitligt resultat som möjligt. Resultaten tyder på en ökning av de befolkade områden och att även de odlade arealerna till viss del har ökat. Detta har skett på bekostnad av den naturliga vegetationen i området som i sin tur har minskat. Inom jordbrukslandskapet har även förändringar skett. Områden av varierande storlek har övergivits, anledningen har till största del varit brist på vatten. Detta har skett både i områden som är beroende av konstbevattning och andra som förlitar sig på nederbörd. Grödorna som odlas har även förändrats till viss del, i flera områden har bönder växlat till att odla banan istället för ris. Två faktorer som påverkat och samverkat till detta är ekonomi och vattenbrist. Många bönder väljer att skifta till att odla banan för det ger en större vinst. Det är dock inte alltid tillåtet, oftast är det bara tillåtet om det råder brist på vatten att odla den mindre vattenkrävande bananplantan vilket i sin tur ger en större vinst för bönderna. I områden där vattentillgången åter har ökat har bönderna fortsatt att odla banan. Denna studie har funnit att Tsunamins påverkan på markanvändningen under ett längre tidsperspektiv har varit begränsad. Till största del har naturlig vegetation blivit påverkad.

Nyckelord: Naturgeografi, Geografi, Sri Lanka, GIS, Fjärranalys, Landskapsförändring

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1. Introduction

1.1 Outline of text

The first chapter consists of three sections, an introduction and background to the study, aim of the study and a description of the study area. In the second chapter the data and the methodology of the study are described. In chapter three the results are presented in a general way, while in the next chapter a more detailed view of these results are presented where some areas are highlighted and discussed more. Chapter five handles the overall discussion of the data, methods and results. The next and final chapter is the conclusion where the questions asked in the aim are answered.

1.2 Background

The country that will be in focus for this study is Sri Lanka. Sri Lanka is an island located in southern Asia, south east of India. Sri Lanka has a population of 19.9 million and an area of 65 610 km^2, making it densely populated with 309 inhabitants per km^2. The capital Colombo is situated in the western part of the country. The country is divided into nine provinces which are further divided into 25 districts. One of these districts is Hambantota where this study took place. A district is then divided into different Divisional Secretariat (DS) divisions; the DS division is finally separated into a number of Grama Niladhari (GN) divisions which is the lowest administrative level Sri Lanka. These function basically on a one village level, only in Hambantota there area close to 600 GN divisions (UNDP, 2007).

Hambantota district was hit hard by the Tsunami in December 2004. This had dire consequences for this poor region in the south (Anputhas et al., 2005). The Tsunami reached Hambantota town with devastating force and with many deaths in the town alone and more then 3000 deaths in the whole district. The fishing industry in Hambantota was greatly affected by this disaster. Due to its long costal zone the district is very dependent on fishery both as an income and as a food source. The Ministry of Fishery reported that as much as 92% of the fishing fleet was affected by the Tsunami. This had big effects on the inhabitants in the region as a big part of there livelihood and food source was taken away. After the disaster great efforts were directed to this sector to be able to restore as much as possible of the loosed material. It was also reported that the Tsunami have had consequences on the farming areas in the region. In IWMI report it states that 350 hectares of paddy fields was damaged by the Tsunami.

In 2003 80% still lived in the rural areas of Sri Lanka where the largest part is employed in the agricultural sector. However in this sector there has been a steady decrease in the employment. In 1990 the sector employed 47% of the workforce while in 1999 the number had gone down to 36%. The main contributing factor was that the rural population has left the agricultural sector to get employment in the growing industry and service sectors. This is seen as a way to raise their income and to get out of poverty (World Bank, 2003). The World Bank expressed there concerns about the decreasing number of employed people in the agricultural sector in there report. They see this as a potential problem for Sri Lankas food supply and their economy.

During the late seventies and early eighties several economical reforms took place and the country changed from a socialistic regulated economy to a free market economy. One thing that happened was that the trade was liberalized. Before the reforms there were strong restrictions on importing agricultural crops that could be domestically grown and the local farmers had a number of benefits. The reforms removed the restrictions and many of the benefits have also gradually been removed. The Paddy market board which played a very important role for the farmers and consumers were closed as resent as 1997. This institute provided fair rice prices for the producing farmer and kept the price at an affordable level for the consumer. These factors have changed the conditions for the farmers. The reforms have lead to a greater "competition" within the agricultural sector, making it harder to survive solely on agricultural work.

One strategy to increase the farmer's income, competition and to spread the economical risk is to diversify the crops that are cultivated. According to World Banks report (2003), where they investigated a survey directed towards farming households during 1999 and 2000, two thirds of the households felt that diversifying their production was a way to raise their income. However the biggest constraints to diversification were reported to be lack of credit, water and technical support.

1.3 Aim of study

The main aim of this study is to develop and evaluate a suitable methodology and to detect land cover changes from the late eighties/early nineties compared to 2006, with focus on the agricultural sector, in Hambantota district.

A second aim is to see if it is possible to see any change in the land cover as a result of the Tsunami that hit the region in December 2004.

The aims can be divided into several questions which the study intends to answer.

- Is the developed methodology suitable for the study area?
- What kind of large scale land cover changes can be observed?
- Have any cultivated areas been permanently abandoned?
- Have the cultivation been more diversified regarding crops?
- If any changes are observed, what are the possible causes?
- Can any changes observed be caused by the Tsunami in December 2004?

1.4 Study area

The study area is the Hambantota district in the southern coastal part of Sri Lanka, figure 1. Hambantota is a wide district, with a shoreline that stretches approximately 130 km covering a large portion of the southern coast of Sri Lanka. This is also reflected in the climate variation seen in the region, ranging from a wet west to the much dryer eastern part.

Hambantota district is divided into 12 divisions, figure 1. In 2001 Hambantota district had a population of 525 370 and has an area of 2 609 km^2, which is approximately 4 % of Sri Lanka's total land area. The regional capital is Hambantota town where all divisional ministries can be found (UNDP, 2007).

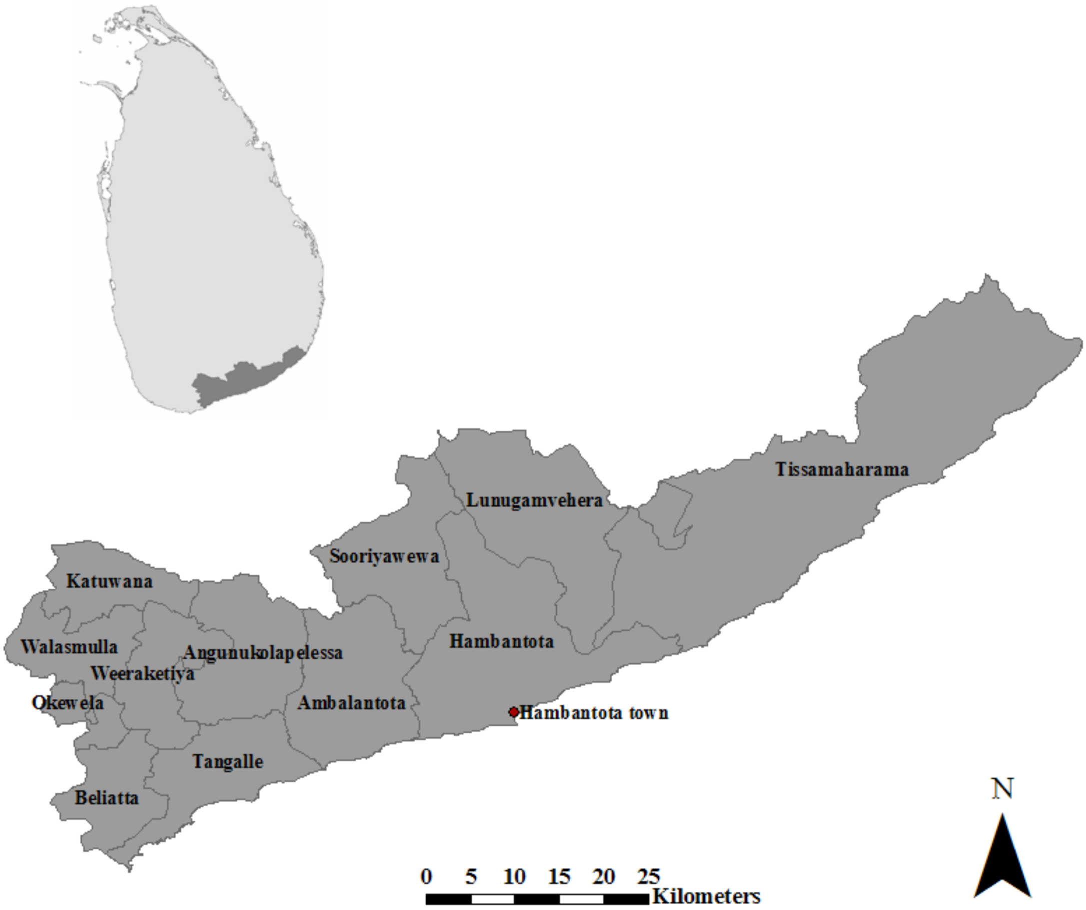

Figure 1. The map illustrates the location of Hambantota district in Sri Lanka and the different divisions the district is divided in. The extent of the district is 456560 west, 659740 south to 578400 east, 727350 north, coordinates in WGS 84 UTM 44N.

The main employment in this region is the agricultural sector where around 40 % of the working population is employed. Due to a large number of domestic and foreign tourists in the region the service and trade sector is another big employer. The foreign tourist's attraction is the many beautiful beaches and the two national parks, Bundala just outside Hambantota town and the larger Yala in the east. For the domestic tourists it is the holy city Kataragama that takes them to the area. Hambantota town is a key connecting town and many people pass through the city on there way to Kataragama. The third largest employer is the manufacturing sector where salt production is an important contributor. The fourth sector where a large number of employees can be found is in the fishing sector. As mentioned before this sector was affected by the Tsunami both economically with much of material and equipment destroyed and socially with many of the fishermen lost in the tragedy. After the Tsunami much of the materials that were destroyed have been replaced and the fishing industry has recovered to some degree (Anputhas et al., 2005).

The landscape in Hambantota has much variation, from dry scrubland on the plains to lush forests in the hills. A dominating sight in the lowland areas is the far stretched paddy fields with the surrounding homesteads. Homesteads are the local name for rural residential areas. A common sight in the whole region is the water reservoirs that are used to supply water to the irrigated cultivation. They are locally known as tanks and ranges in size from just a hundred meters in width to the larger ones that are several kilometres long. In the more remote areas the small scale farming is common and the area is more dominated by scrublands.

The main agricultural crop production in Hambantota and also the country as a whole is made up by rice production. The district contributes to 5 % of the total rice production and is the 7th largest rice production district in Sri Lanka (Anputhas et al., 2005). The rice production is very important in Sri Lanka and is considered to be the most important food source. In 1990 it stood for 45 % of the calorie and protein intake per capita (SAAPE, 2003). Paddy rice requires lots of water and is therefore grown in paddy fields. These fields are terraced to keep the water on the fields. Much of the paddy fields are irrigated but there are also fields that are solely dependent on precipitation. The irrigated paddy fields are supported by a mace of channels that branches out from the water reservoirs. The water flow in the channels is controlled so the right amount of water reaches the fields. The fields which are sustained by precipitation are usually only used for rice cultivation during the wet season. During the dry season farmers sometimes grow other crops that are not so water dependent, uses the fields for grazing or put the fields under fallow.

Another important crop which is relative new in many parts of the region is banana. Banana plants also require a lot of water and are therefore in general grown in paddy fields. The water demand is however not as large as it is for rice and it is common that farmers grow banana in the drier part of the paddy fields where they do not have enough water for rice cultivation. The result of this is small patches in the corners of the paddy fields where the farmers grow banana. But there are some areas in Hambantota where banana is grown in a much larger scale and the banana cultivations are bigger than the rice cultivation. A banana plant is grown for about five years and after this time they are removed and rice is usually grown again. The banana plant is more nutrient demanding and this kind of crop rotation keeps the ground from being depleted.

The homesteads also have another important usage apart from residential, it is also used as gardens. A typical homestead is a couple of hectares where a variety of different crops, fruit trees and coconut trees are grown. The homesteads are a big supplier to the regional food production. Much of the production is used within the household but there is also a big demand for the products in the markets and the money it contributes with serve as a good extra income for the households.

A hidden supplier for the agricultural markets is the products that originate from the slash and burn cultivations locally known as chena cultivations. This kind of cultivation is mainly located in the more remote scrublands and forest areas. The farmers burn down the natural vegetation and grow crops there for a couple of years and then move to a new area. The farmers that practice this kind of farming are the ones who can not afford to buy or rent the much more productive paddy lands. The areas that are obtained by the farmers is owned by the government which makes this kind of farming illegal, however it is something that is more or less allowed and it is not a prioritized matter for the government to deal with.

The climate in Hambantota is influenced by the South Asian monsoon which gives different climates in the far stretched district. The district is divided into four ecological regions, figure 2. The largest part in the east is categorized as dry zone, which is divided in two zones where the driest is more to the east and southeast. The annual precipitation in the dry zone is between 750 and 1000 mm. The intermediate zone is located in the west with an annual precipitation of 1000 and 1500 mm and the wet zone in a small part of the western corner with an annual precipitation of 1500 and 2000 mm. These different ecological regions all have a characteristic climate (Peris, 2006).

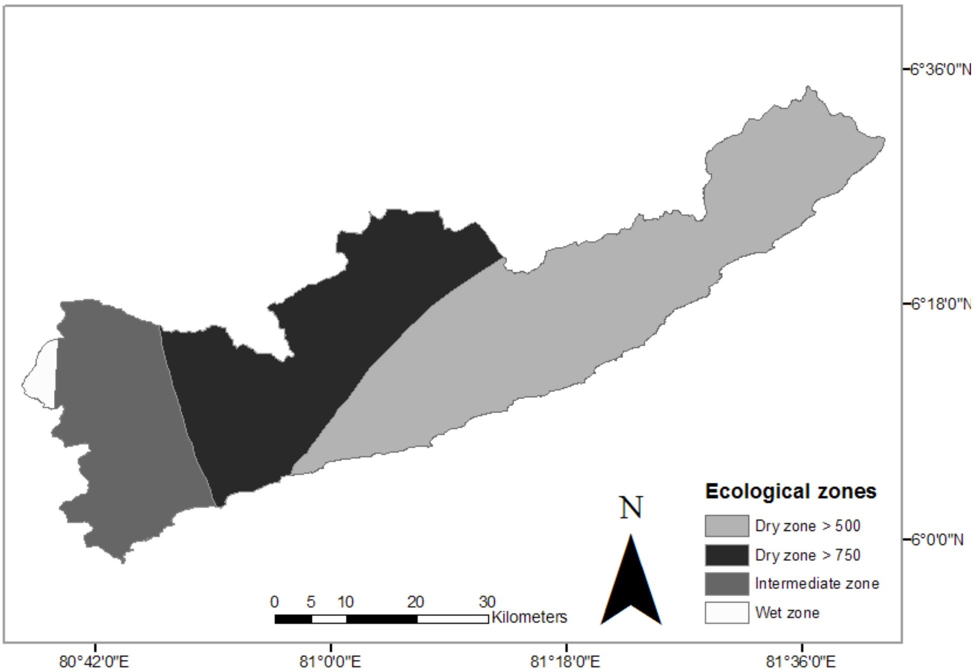

Figure 2. The figure shows the ecological zones in Hambantota district.

2. Materials and Methods

The workflow for the method is illustrated in figure 3, where the first step was to select and to acquire the satellite images that were going to be analysed. The second was the pre-processing of the images that were used as input for the classifications and Change Vector Analysis (CVA). The field data that were collected in Sri Lanka were used to improve and to evaluate the classification and to use as reference data together with the result from the classifications and Change vector analysis to detect land cover changes.

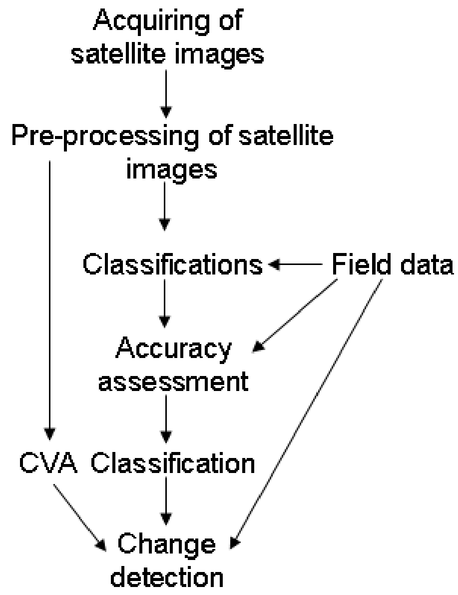

Figure 3, illustrates the workflow for the study.

2.1 Materials

2.1.1 Satellite data

The main source of satellite images that were analysed in this study was from the Landsat program. The main reason that the Landsat program was used was because of its long temporal coverage and because of good availability of its images to the general public. The earliest Landsat sensor is called Multi Spectral Scanner (MSS) and was launched already in 1972 while the Thematic Mapper (TM) satellite has coverage from 1982 and Enhanced Thematic Mapper + (ETM+) from 1999. In this study images from the TM and ETM+ sensor have been used. The spectral sensitivity is the same between the sensors and can be seen in table 1 (Lillesand et al, 2004).

The spatial resolution for both sensors and all bands except band 6 is 30 meters, band 6 has a resolution of 120 meters for TM and 60 for ETM+. The other major difference between them is that the ETM+ sensor also has a panchromatic band with a resolution of 15 meters which the TM lacks.

Table 1. The table shows the different spectral bands for Landsat TM.

Band	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Wavelength (µm)	**0.45 - 0.52**	**0.52 – 0.60**	**0.63 – 0.69**	**0.76 – 0.90**	**1.55 – 1.75**	**10.4 – 12.5**	**2.08 – 2.35**
Nominal Spectral Location	**Blue**	**Green**	**Red**	**Near IR**	**Mid IR**	**Thermal IR**	**Mid IR**

Landsat data is recognized by many and have been used in many studies and different applications. Landsat is very suitable for vegetation surveying and land cover/use change studies and is frequently used for this purpose. In studies by Brondizio S et al (2002) and Rogan et al (2002) changes in land use/cover were investigated by using Landsat data.

The Advanced Very High Resolution Radiometer (AVHRR), provided by National Oceanic and Atmospheric (NOAA), was the second satellite source that was used in the study. The dataset that was used from AVHRR was a NDVI derived product that consisted of two NDVI values for each month. The temporal coverage was from 1982 to 2005 and with a spatial resolution of 8 × 8 km.

The final satellite source was the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra platform. MODIS like AVHRR provide a finished NDVI product, and also with two values each month. MODIS has a temporal coverage from 1999 to present and the spatial resolution of the product is 1*1 km.

2.1.2 Selection of satellite images

There were three time periods that were of interest, Landsat images that was as old as possible, images that were as recent as possible and images from before the Tsunami that occurred December 2004.

To find suitable images to study and analyse, there are several image properties to take into consideration. The most important and the more obvious factor is to minimize the cloud cover as much as possible in the images. If there is a large cloud cover no interpretation can be done at all. Further the seasonal change has to be taken into account. The phenological difference between the different seasons has a great impact on the reflectance from the land cover. Therefore images should be chosen from the same season. For this study were the agricultural areas are in focus it is crucial to be able to separate agricultural land from other vegetation types. To make this difference more pronounce, the seasonal growing pattern of crops, primary rice, were studied to find a suitable time period to look at.

In the study region two major crops seasons can be identified. The Maha season where the biggest area is cultivated coincides with the wet season and stretches from September to March. Yala is the season during the dry period and stretches from April to August. During this period the cultivation is highly dependent on water from irrigation schemes. Much of the rain feed agricultural area is not cultivated during this period. The season that was selected to be the most suitable time period was the Maha season, during this period all the paddy fields that are used should be cultivated. One of the aims in the study was to see if there were any abandoned paddy fields in the district and during this time these fields should be easier to separate from the cultivated paddy fields.

To find the optimal time to be able to separate rice cultivation from other vegetation the growing pattern of rice was observed in a study done by Oguro et al (2001). It was found that for this study the optimal time would be in the end of the rice growing stage when the rice paddy fields have a high vegetation response or when the fields already have been harvested and have a minimum vegetation response. If the rice paddy fields are in any if these two states it would be easier to separate them from any other possible cultivation in the paddy fields. If the paddy fields have been abandoned the field should have a quite low vegetation response. This would also make it possible to separate from the rice cultivation.

Landsat images are organized in the Worldwide Reference System (WRS) where the earth is divided into longitudinal paths and latitudinal rows. The extent of each scene is 185 * 185 km, and from these larger scenes sub sets were made to have a more manageable image size that only covered Hambantota district. Figure 3 shows the image extent after sub setting and how the study area is divided between two Landsat scenes, path 140 row 56 for the eastern part and path 141 row 56 for the western part.

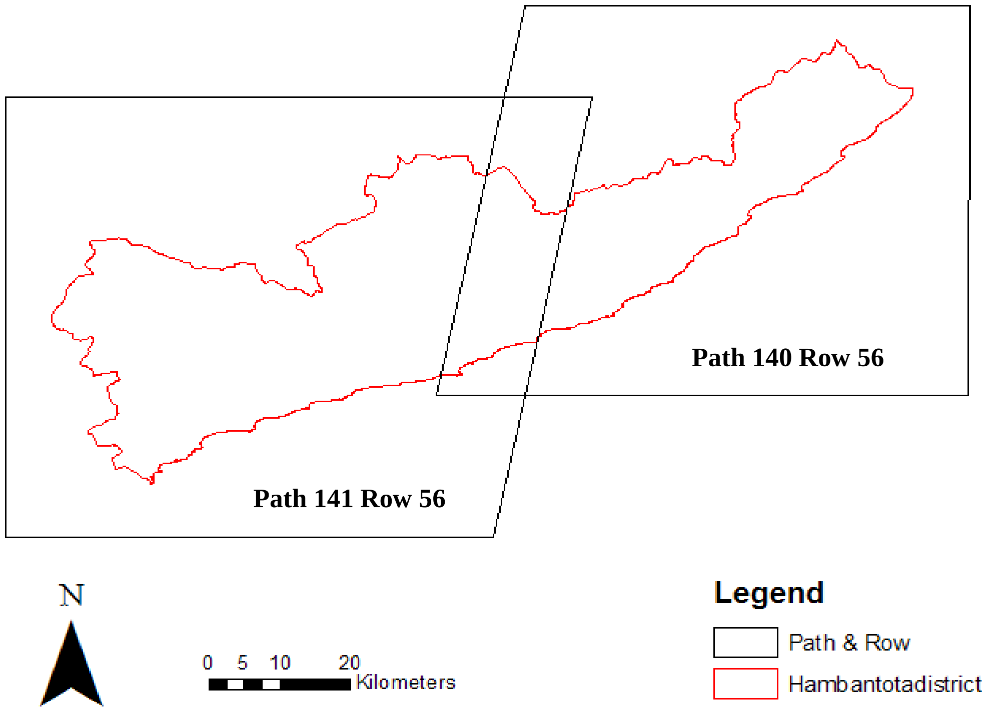

Figure 3. The figure shows the extent of the satellite images after sub sets were made and how Hambantota district is divided by different Landsat scenes. The extent of the district is 456560 west, 659740 south to 578400 east, 727350 north, coordinates in WGS 84 UTM 44N.

To get a complete coverage over the area two sets of images were needed. Each set of images was treated separately during the analyse of the images. In total six different Landsat images were acquired, two ETM+ and four TM, table 2. The two ETM+ images that were used in the study were downloaded from International Water Management Institute (IWMI). One TM image was downloaded from Global Land Cover Facility (GLCF) and the other three images were bought from GIS Informatics and Space Technology Development Agency (GISTDA, 2007), which is the ground receiving station for Landsat images in the south Asia region.

Table 2. The acquisition dates for the six Landsat TM and ETM images and the data source.

Satellite source	Path 141	Path 140
Landsat TM	**1993-02-12 GLCF**	**1988-01-23 GISTDA**
Landsat ETM+	**2001-03-14 IWMI**	**2001-03-07 IWMI**
Landsat TM	**2006-04-05 GISTDA**	**2006-04-30 GISTDA**

2.1.3 Ancillary data

To have some prior knowledge of which land covers that could be found in the study area land cover maps from 2001 and 1983 were investigated. The two maps were used as a form of reference data when separating the different classes and selecting training areas during classification process. These maps are created from aerial photographs which give it a quite high detail level, the manufacturers is the Survey department in Sri Lanka (2007). The classes in these maps were somewhat different from the classes used in this study, where some were divided into several land cover/use classes. But still they were comparable and worked well as additional information.

Another form of ancillary data was high resolution satellite images originated from the Quickbird satellite sensor. The images covered an area in the remote eastern region where the Yala national park is located. This area was not possible to reach during the field work so this data worked as a supplement for the field data.

The elevation model was used to get further information about the areas that were damaged by the Tsunami.

Land-cover maps -	Originates from the Survey Department in Sri Lanka from the years 2001 and 1983.
Quickbird data -	Coverage over parts of the more remote areas in the eastern part of Hambantota. The images were registered in 2002-12-10.
DEM -	Elevation model that originates from USGS

2.1.4 Field study

2.1.4.1 Collection of GPS Points

A major part of the field study in Hambantota district consisted in looking at training areas, collecting validation points and ground control points with the help of a GPS. The training areas was visited in the field to ensure that they consisted of the correct land cover class so they could be used to improve image classification, validation points were collected to assess the accuracy of the final classifications and the ground control points were used for the geometric correction of the images.

The method of collecting the sampling points was not done randomly, mainly by two reasons. The first reason is that the areas that could be selected can be very hard to reach because the lack of infrastructure. The second reason is if a completely random selection process is used entire land cover classes can be without sample points. For the validation that was done of the final classification it is important to have sampling points in all the different classes. These two reasons and the fact that you can cover a larger area during a shorter time period made road sampling a suitable method for the study area. Road sampling is conducted by taking ground control points in a certain interval along roads. In this study one point, 150 meters away from the road on each side was collected every three kilometres. The different routes were selected with the goal to cover as large area as possible and to cover all the different land cover classes.

A condition for the validation points and training areas were that the area should be minimum 100*100 meters and to have a homogenous land cover. The extent of the area was selected to minimize the spatial error of the points. The combination of the geometrical error from the GPS positioning and the satellite images, which had a spatial resolution of 30*30 meters, a smaller area than 100*100 meter were found to be too small. For each validation point the land cover class was noted.

None of the images that were bought or downloaded had a satisfactory geometrical reference system. None of the images were completely aligned with any of the other images and between the GPS points collected and the images there could be a 200 meters spatial difference. Therefore GPS points were collected to use as GCP when rectifying the images. The positions were selected to get an even distribution over the entire study area which is imperative when doing a geometric correction. Landmarks that were visible in the satellite images and possible to visit in the field were selected as ground control points. The landmarks selected could be road intersections, temples or other larger buildings.

2.1.4.2 Interviews

Interviews were made to have additional information to support the result from the change detection. The interviews were directed towards officials that had a divisional knowledge about the land cover. To get a complete coverage over the district all 12 divisions were visited. All the officials that were interviewed worked at the divisional planning secretariat. The most suitable person to be interviewed was selected by the Assistant Director in the chosen division. The most common employment of the persons interviewed was Land-use planning assistant.

There are several different techniques for interviewing. A common way to divide them is to which extent they are controlled. Then there are usually three different techniques a structured, semi structured and unstructured technique.

Structured interviews are similar to questionnaires and are performed by having the same standardized questions in all the conducted interviews. The semi-structured method uses pre-selected themes that are quite openly discussed and the questions are not predefined. The third, unstructured technique is conducted by having a very open discussion where the person being interviewed can take the discussion in any direction (Desai and Potter, 2006).

In this study a semi-structured interviewing technique was selected because of its possibility to be well prepared and to have an open discussion. The following themes were discussed during the interview:

Major land covers/land uses in the division

Land-use/Land-cover change & Cause of change

Economical conditions for farmers

Modernization of the agricultural sector

Aids given for agricultural production

If any crop or land use is preferred by farmers or government

Changes in forest cover

Tsunami related land-cover/land-use changes

The first theme was chosen to be able to get an overview of the land cover in the division. The second was the primary category where the information about the land cover change was handled. The other areas that were discussed were more to find out reasons to why the possible changes had occurred.

2.2 Pre-processing of satellite data

2.2.1 Geometric corrections

None of the images had a correct geometrically reference system. Therefore GCP's were collected during the fieldwork for locations that were possible to identify in the satellite images. The 2001 ETM+ image from each dataset was corrected using the collected points and then served as a reference image that was used to correct the other images. These two images were selected because they also have a panchromatic band which has a better spatial resolution then the other spectral bands. The resolution is 15 meters instead of the 30 meters that the other bands have. The increase in resolution improved the ability to locate suitable ground control points in the images significantly. The collected ground control points only covered Hambantota district so it was only this area that could be corrected geometrically. Therefore during this step there were subsets made of the images to remove the area surrounding Hambantota district.

In the resampling process a nearest neighbour method was used to preserve the original pixel value. The pixel RMS error did not exceed 0.45 for any of the dates, an upper limit should be 0.5 pixel. The images were corrected to the global Universal Transverse Mercator (UTM) zone 44 N with WGS 84 as ellipsoid.

2.2.2 Radiometric correction

Radiometric correction is conducted to reduce the spectral differences in surface reflectance between the images and to reduce the noise. Factors that can affect the reflectance are e.g. the sun zenith angles and earth sun distance. When converting the raw DN values to at-reflectance some of these differences are removed.

Table 3. Slope and Intercept values for conversion of TM DN values to ETM that were used in equation 1.

Band	Slope	Intercept
1	**0.94**	**4.29**
2	**1.77**	**4.73**
3	**1.54**	**3.98**
4	**1.42**	**7.03**
5	**0.98**	**7.02**
7	**1.30**	**7.66**

The first step in converting the raw data was to take advantage of the better ETM+ calibration. Equations and values that were used in this method come from USGS (2006) and are originates from a study by Vogelmann et al (2001) where comparison between ETM+ and TM images were made. The TM DN values (DN5) was converted to ETM+ DN values (DN7). After this conversion the images were treated as ETM+ images. The following equation was used.

*DN (7) = DN (5) * (Slope + Intercept) (Equation 1)*

Next step were to convert the DN values to spectral radiance. The following equations and the gain and bias values from Markham and Barker (1986) were used. The gain and bias values corrects for errors that originate from the sensor during image registration. The spectral radiance was then used to calculate the at-reflectance.

*L (i) = DN (i) * Gain (i) + Bias (i) (Equation 2)*

i = ETM+ & TM band number
L = spectral radiance at sensor aperture in $mW•cm^{-2}•ster^{-1}•\mu m^{-1}$

Table 4. Gain and Bias values for the TM images used in equation 2.

Band	Gain	Bias
1	**0,76**	**-1,52**
2	**1,44**	**-2,84**
3	**1,04**	**-1,17**
4	**0,87**	**-1,51**
5	**0,12**	**-0,27**
7	**0,07**	**-0,15**

The final step was to convert the radiance to at-reflectance using equation 3. This equation normalizes for solar irradiance and reduces the variability between the different scenes. The resulting at-reflectance values range from 0 to 1.

$\rho_p = \pi * L_\lambda * d^2 / ESUN_\lambda * cos(\theta_s)$ *(Equation 3)*

ρ_p = unit less effective at-satellite planetary reflectance
L_λ = Spectral radiance at sensor aperture in $mW•cm^{-2}•ster^{-1}•\mu m^{-1}$
d = Earth-Sun distance in astronomical units
$ESUN_\lambda$ = Mean solar exoatmospheric irradiances in $mW•cm^{-2}•ster^{-1}$
θ_s = Solar zenith angle in degrees

2.2.3 Histogram adjustment

Most of the images that were used were hazy, which is a result of Rayleigh scattering. The scattering effect is additive and affects mainly the shorter wavelengths and reduce the contrast in the image and makes interpretation harder. There are many different models to adjust for this undesired effect where several more advanced need ground measurement from the site during registration of the image (Brondizio et al. 2002). In this study a simpler model called histogram adjustment were applied on the images.

The model assumes that the scattering is uniform over the entire image and utilizes the fact that the minimum pixel value in the image should be zero. If the pixel value is larger then zero the model say that this is due to atmospheric scattering. By evaluating the histograms from different pixels and all the wavelength bands from several land covers and locations in the image threshold values were selected. Adjustments were then done by subtracting the minimum value from the data in the different wavelength bands. By applying this model atmospheric scattering is reduced (Jensen, 1986), and the histograms from the different images become more comparable and a better result can be achieved.

2.2.4 Tasseled cap

The tasseled cap is a weighted linear transformation based on Landsat TM/ETM+ bands 1-5 and 7. The result of the transformation is different indexes that were used as input for the CVA that will be explained in section 2.3. The transformation was original constructed by Kauth and Thomas (1976) and is originally based on Landsat MSS data. The transformation was applied on Landsat TM data where two different methods were constructed. The first were in a study by Crist and Cicone (1984) where they calculated it on raw DN values. This was further developed by Crist (1985) to be used on TM data. In 2002 a third method was created by Huang et al (2002) based on Landsat 7 at-reflectance. The values used in this study come from Huang´s report.

The result of the transformation done on Landsat 5 and 7 values is six different indexes. For the transformation calculated on Landsat 7 at-reflectance values the first three components explains 97% of the spectral variance (Huang, 2002). In the study the Brightness and Greenness indexes was finally used. This selection was based on that these two were thought to be of greater use in the monitoring of the vegetation. The wetness index was primary an indicator of soil moisture which was not that useful in this study.

The Brightness is a weighted sum of all six bands that are used and gives the total reflectance from the ground. A less vegetated area gives a higher value than a more vegetated surface in this component.

The Greenness responds to a high absorption in the visible spectral band and a high reflectance in the near infrared bands. This component is very similar to the widely used normalized difference vegetation index (NDVI) that is calculated on the red and near infrared spectral bands (Crist & Cicone, 1984).

The two indexes were calculated with equation 4 for brightness and 5, for Greenness using the coefficient in table 5.

$$Brightness = ETM1*b1+ETM2*b2+ETM3*b3+ETM4*b4+ETM5*b5+ETM7*b7$$
(Equation 4)

$$Greenness = ETM1*g1+ETM2*g2+ETM3*g3+ETM4*g4+ETM5*g5+ETM7*g7$$
(Equation 5)

Table 5. The tasseled cap coefficient used in equations 4 and 5, and there symbols used in the equation.

Band (B)	Brightness (b)	Greenness (g)
1	**0,36**	**-0.33**
2	**0.40**	**-0.35**
3	**0.39**	**-0.46**
4	**0.70**	**0.70**
5	**0.23**	**-0.76**
7	**0.16**	**-0.26**

2.2.5 Seasonal fitting

The choice of satellite images to use in the study was mainly governed by the cultivation season but it was still important to be able to see where in the natural season the images were located. It is also important to see if the years that was studied had any anomalies in their NDVI values through out the year that could affect the analyse of the images.

The seasonal fitting was done by comparing the date when the main Landsat satellite data was registered with NDVI seasonal values that originates from NOAA AVHRR and Terra MODIS data. The NDVI values for the whole year were studied to be able to locate the image in the seasonal vegetation cycle. The complete dataset was also examined to see if there were any anomalies for the years that were studied.

AVHRR had a temporal coverage until 2005, for 2006 the MODIS dataset was used. The different sensors had different spatial resolution so to get the same extent an 8×8 pixel area was extracted from the MODIS dataset with the same coordinates as the NOAA dataset that was used. To be able to see the vegetation cycle without any anthropogenic interference an area with natural vegetation cover was selected.

The NDVI is calculated with the following equation.

$$NDVI = (NIR - RED) / (NIR + RED) \quad \text{(Equation 6)}$$

2.3 Change Vector Analysis

Change vector analysis (CVA) is basically an extension of an image differencing where for example one NDVI image is subtracted from another to get the vegetation change. The big advantage with the CVA is that several indexes can be used as input which results in a much more detailed information of what kind of change that has occurred and not only a decrease or increase in one index. This is however also the disadvantage with the method because it can at the same time make the interpretation harder and more time consuming (Lu et al. 2004).

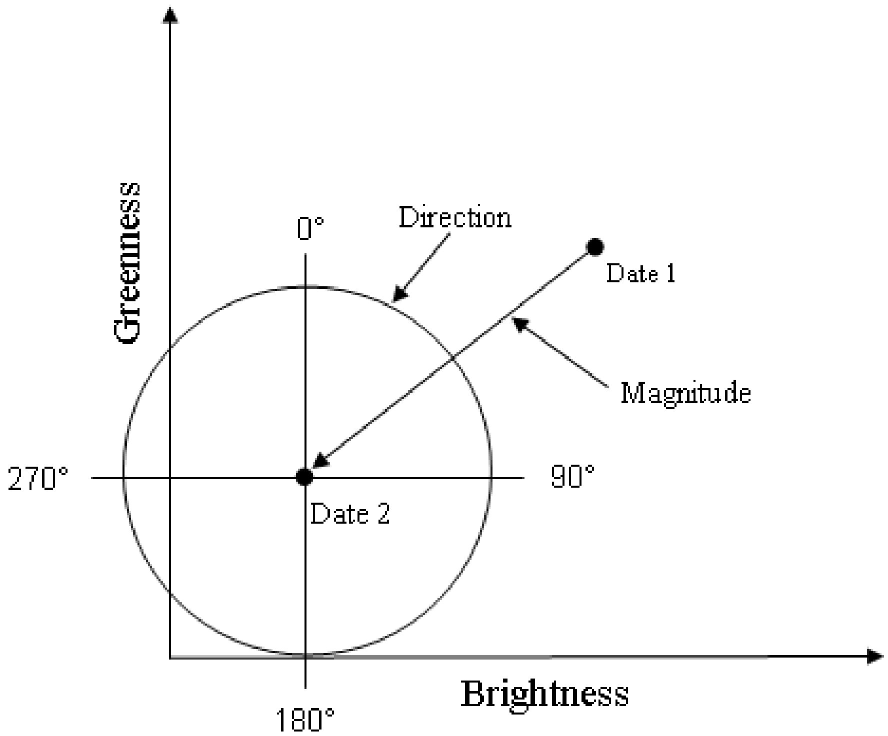

Figure 4. The figure illustrates how a pixel undergoes a change between two dates in two dimensional space. The tasseled cap indexes brightness and greenness are used as input for the different dates.

An existing CVA algorithm in the IDRISI Andes software was used. The function uses two images from each time period that are being investigated as input. In this case the tasseled cap indexes brightness and greenness from the earlier dates were compared against 2006 indexes. The result is two information images one direction and one magnitude image. Figure 4 illustrates in two-dimensional space the change that a pixel undergoes between two dates where a vector describes the direction and magnitude of the change. For a given pixel the magnitude is calculated as the Euclidian distance between the two dates and shows how large the change is. While the direction explains what kind of change that the pixel has undergone with values ranging from 0 to 360°, where each value represents a specific change between the dates. The change direction for a pixel is interpreted from date 1 to date 2. For example is a value of 45° a decrease in both brightness and greenness 2 between the two dates, figure 4.

2.4 Land Cover Classifications

One aim of the study was to test two different classification methods on the images. The two different methods were a Supervised Maximum Likelihood and a knowledge based classification. Both methods use training areas to extract spectral signatures for the different land cover classes. If it was possible the distribution and extent of the training areas was kept between the different classifications to get the same areas as input for the spectral signatures. This was done to minimize classification differences unrelated to actual land cover change between the different image dates. The classifications used the calculated at-reflectance from the different spectral bands as input.

To get as good result as possible the two classification methods were first tested on the 2006 images. 2006 was chosen because this year was closer in time to the collected field data that was used in the accuracy assessment. The method that gave the best result in the accuracy assessment was then applied on the other images. The result was used for a post classification comparison between the different time periods and in a combination with the CVA products to detect land cover changes.

2.2.1 Land cover classes

The land cover map from 2001 and other literature (Peiris, 2006) showed what kind of land cover types that could be expected in the area. The land cover types that were finally used in the classification were selected based on relevance to the study and to what extent the different types could be identified in the satellite images. In the classification the land cover class scrubland was divided in two sub classes, sparse scrubland and dense scrubland. However in the field these two subclasses were not possible to separate so the two classes were combined into one scrubland class during the accuracy assessment. This will further be discussed in section 5.2.

The different land cover classes that could be identified were:

Abandoned paddy	Recently abandoned paddy land due to lack of water etc.
Banana plantation	Planting of banana trees.
Bare ground	Unproductive land, rocks and beaches.
Built up area	Residential, industrial and other urban spaces.
Forest	High growing natural vegetation with more then 45% tree crown coverage.
Homesteads -	Residential areas consisting of houses surrounded by gardens, includes smaller cultivated areas with fruit trees, coconut trees and other crops.
Rice paddy fields	Paddy land with rain feed or irrigated rice cultivation.
Scrubland	Low vegetation with more than 30% ground coverage of bushes and trees up to 45% canopy cover.
Water	All natural and man made water bodies.

2.2.2 Supervised Maximum likelihood classification

The first classification algorithm tested was a supervised Maximum likelihood which is a method that has been used in studies like Mas (1999). The method assumes that there is a normal distribution of the spectral values for all different spectral bands that are used.

Based on the training data that is provided by the user the algorithm calculates the probability for a given pixel to belong to each of the possible land cover classes. The class that has the highest probability will be assigned to the pixel. Figure 5 illustrates the probability for a given pixel to belong to different classes.

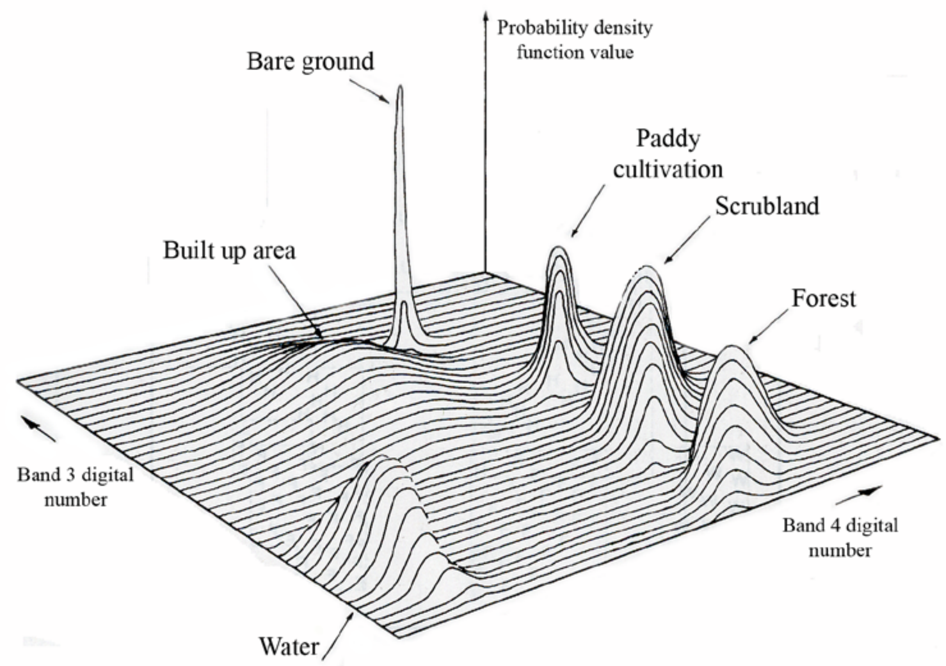

Figure 5. The figure illustrates how the Maximum likelihood classifier works in a three-dimensional graph, where the height is the probability values for each class for a given pixel, (Jensen J,R, 1986).

2.2.3 Knowledge based classification

The second classification algorithm used a built in function in the IDRISI Andes software, a maximum likelihood with prior probability. This was combined with visual interpretation and the result from the CVA. This method is more similar to a knowledge-based classification where the result is not only dependent on the class spectral signature but the user can influence the classification with additional information.

Different from the probability values used in the maximum likelihood algorithm, which are calculated based on the training data, the prior probability function makes it possible for the user to indicate how big proportion a certain land cover has of the study area. The user can choose if any class is more likely to exist in the whole image or one or several classes could be limited to specific areas. The second option was used in the study and several areas were chosen to contain a limited number of classes. All the classes that were not restricted to any area were given an equal prior probability to exist in the rest of the study area. This was done because the extent of the different classes was not known in advance.

Land cover types that were hard to make a good classification of and had a low accuracy with the maximum likelihood algorithm were if possible more restricted in this method. In a study by Strahler (1980) the use of a maximum likelihood with prior probability is recognized as a good way to improve the accuracy of a classification.

The first step in the process was to visually separate areas that were made up by known land cover classes. The selection was made by visual interpretation of the satellite images and cross checking it with the land cover map from 2001 and with the knowledge gained from the field observations.

The second step was to digitize these selected areas. The areas that were digitized were paddy areas which was by far the largest separated area, the smaller built up areas and a third area where it was known that bananas were growing outside the paddy fields, figure 6. These layers were then revised for each of the images.

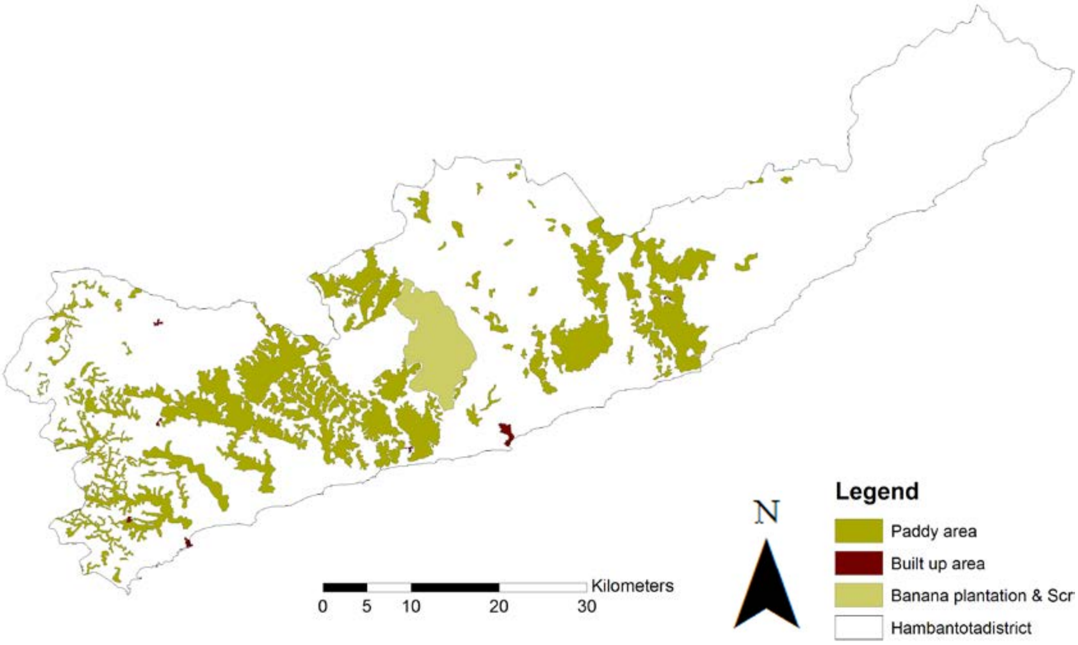

Figure 6. The figure shows the spatial restrictions that were set for some of the classes in the 2006 classification. These areas were revised for the different images and its classifications. The extent of the district is 456560 west, 659740 south to 578400 east, 727350 north, coordinates in WGS 84 UTM 44N.

The third step was to restrict the different digitized areas to certain land cover classes. The first area was the paddy area which was restricted to four classes, rice paddy fields, homesteads, banana plantation and abandoned paddy fields.

Rice paddy fields could exist everywhere within the digitized area without any restrictions. The borders of the paddy fields were exclusively made up by homesteads and it was also common that areas in the middle of the fields consisted of homesteads. So to ensure that the border and other areas that could be inside the digitized layer were classified correct the homestead class was added as a possible class that also could exist everywhere in the digitized area.

For the banana plantation class an additional condition was added. For a pixel to be classified as banana plantation there had to be a change registered in the change vector analysis within the paddy fields when comparing the earlier images from 1988 and 1993 with the 2006 images. If there had been any banana planted in the fields a change would have been registered in the CVA.

The abandoned paddy class had the same condition as the banana plantation class, a change had to be registered in the CVA for the class to exist. This class had a quite low greenness value and should therefore differ from paddy fields during this time and a change would be registered. These additional restrictions to the class were possible to apply because there are no records that there were any banana plantations or abandoned paddy during the earlier time period in the region. During the interviewees this fact was confirmed when the interviewees talked about banana as a relative new crop in the region.

Because the seasonal growing pattern of rice varied between different areas in Hambantota the CVA change direction could be different even if the same land cover change had taken place. If an area with rice cultivation was in a late succession stage it had a high greenness value. If the area was abandoned a decrease in greenness should be registered while if the rice were in an early stage the change would have been the opposite. This difference in CVA direction could also be applied on the banana plantation and no special direction could be identified to it was therefore possible for all pixels where a change had taken place to be classified as abandoned paddy or banana plantation. For both land cover classes this limited the spatial extent.

The second area that was restricted to certain classes was a region where there was banana growing outside the paddy fields. This region was observed in the field and was the only area of its kind that was found. The area is located in Sooriyawewa district which is known to grow a lot of banana. In the area surrounding these fields the dominating land cover consisted of scrubland. So for this area banana plantation and scrubland were the possible classes.

The third and final area that had restriction was the town areas. The rural towns in Hambantota have more trees and less paved roads then larger towns. This contributes to a quite large difference in spectral reflectance within a town making it hard to separate from surrounding environment. For the town areas that were digitized, built up area was the only possible class. This class had a very limited spatial extent which figure 6 illustrates.

2.2.4 Accuracy assessment

An accuracy assessment was made for the classifications. The result is an error matrix where the overall, producer's and user's accuracy are given. The overall accuracy shows how big percentage of all the validation points that are correct classified. Producer's accuracy is the probability that an area in the field chosen by chance is classified correct whiles the user's accuracy is the probability that an area on the map randomly chosen is classified correct.

The last step was to calculate Kappa values on the classifications. The Kappa coefficient indicates how much better the classification is than if the classes would have been randomly distributed over the image. Kappa was calculated both for the entire classification and for the individual land cover classes. The following equation is for the individual classes, when calculating it for the entire classification you add the variables for the different classes together.

$$Kappa = (pii - qii) / (pi - qii) \quad \text{(Equation 7)}$$

pii   *number of correct classified points for class i*
pi   *number of classified points for class i*
qii   *number of expected points when completely random for class i*

The accuracy assessment was calculated for the 2006 image classifications. To get an easier overview the classification result from both the eastern and western part was combined into one complete land cover map over the entire district, figure 21. Two assessments were made, one on the Maximum likelihood classification and one on the knowledge based classification.

3. Result

3.1 Field study

3.1.1 Ground Control Points

In total 576 points were collected and used in the validation of the different classifications. The points were collected to get an even distribution over the entire district and if possible over different land cover types. The collected points were distributed over the land cover types according to table 6. The classes with the most coverage are homestead, rice paddy cultivation and scrubland. These three classes were by far the most dominating classes in the district. The other classes do not have the same extent and was harder to get points in.

Table 6. The distribution of sampling point taken out in the field between the land cover classes.

Land cover type	Collected points
Water	**36**
Rice paddy cultivation	**143**
Banana plantation	**57**
Homestead	**169**
Scrubland	**128**
Bare ground	**9**
Forest	**24**
Built up area	**8**
Abandoned paddy	**6**
Total number of points	**576**

The collected ground control points that were used for the geo-correction of the 2001 images were also evenly taken out over the region. For these points it was very important to get an even distribution as possible to get a good geo-correction. In each image there were 15 points that could be identified in the satellite image and on the ground.

3.1.2 Interviews

There were 17 interviews made in total. These covered all 12 divisions and if it was possible more then one person was interviewed. The district land use planning office in Hambantota was also visited and the director was interviewed with questions that were more directed to the district as a whole and not to the divisional level as the other interviews. Table 7 illustrates the answers to the questions about the change in different land cover class types. The questions about the land cover change focus on changes that had occurred since the late eighties and early nineties. In Ambalantota division the interviewee were newly employed and could not answer the questions about land use change.

In nine of the divisions the interviewed answered the question if there were abandoned paddy fields in their division, 7 said that there were, 2 said that it did not exist in there division. According to the interviewees it was mostly smaller rain feed paddy fields that was abandoned because the lack of water during the rainy season. The lack of water could also be a result of tanks that were damaged or insufficient filled during the wet season. One larger area in Tangalle had paddy fields that were abandoned because of high salinity in the ground.

The change that was quite uniform between the different divisions was that the homesteads have increased. In nine of eleven divisions that answered they reported that the area had increased.

The extent of the rice paddy cultivation has increased in 3 divisions while it remained the same in 7 divisions. Lunugamvehera was the only division where a decrease in the rice fields had taken place. In this area the rice paddy cultivation had turned into banana cultivation. In the other divisions where banana was grown it was in much smaller scale and did not affect the total area under rice paddy cultivation.

In 7 divisions the natural vegetation of either scrubland or forest was reported to have decreased. Where a decrease in these land cover types had taken place there had been an increase in homesteads or paddy cultivation.

Table 7 illustrates the result of the interviews made in the different divisions. The symbols means the following, ↔ no change has taken place, ↓ a decrease in the extent of the land cover, ↑ an increase in the extent, × not a land type in division and an empty space no answer to the question.

	Forest	**Homesteads**	**Rice Paddy fields**	**Scrubland**	**Abandoned Paddy**	**Banana plantation**
Ambalantota						
Angunukolapelessa	↓	↑	↑		×	↑
Beliatte	×	↔	↔	↔	↑	
Hambantota	×	↑	↔	↓	↑	
Katuwana	↔	↑	↔	↔	↑	↑
Lunugamvehera	↓	↑	↓	↓		↑
Okewela	↓	↑	↔	↓	↑	↑
Sooriyawewa		↑	↑	↓	↑	↑
Tangalle	↔	↔	↔	↔	↑	
Tissaamaharama	↔	↑	↑	↓	×	
Walasmulla		↑	↔			
Weeraketiya		↑	↔	↓	↑	

3.2 Seasonal fitting

Figure 7 shows the NDVI trend for the period between 1982 and 2006. A Gaussian trend line was used to smooth the NDVI trend and to make it more comprehensive. The seasonal variations vary quite much where some years have larger variations than others. For the years where images were acquired it was foremost 1988 and 1993 that had a higher variation in the season values. A close up of the NDVI trend for 1988 is seen in figure 8.

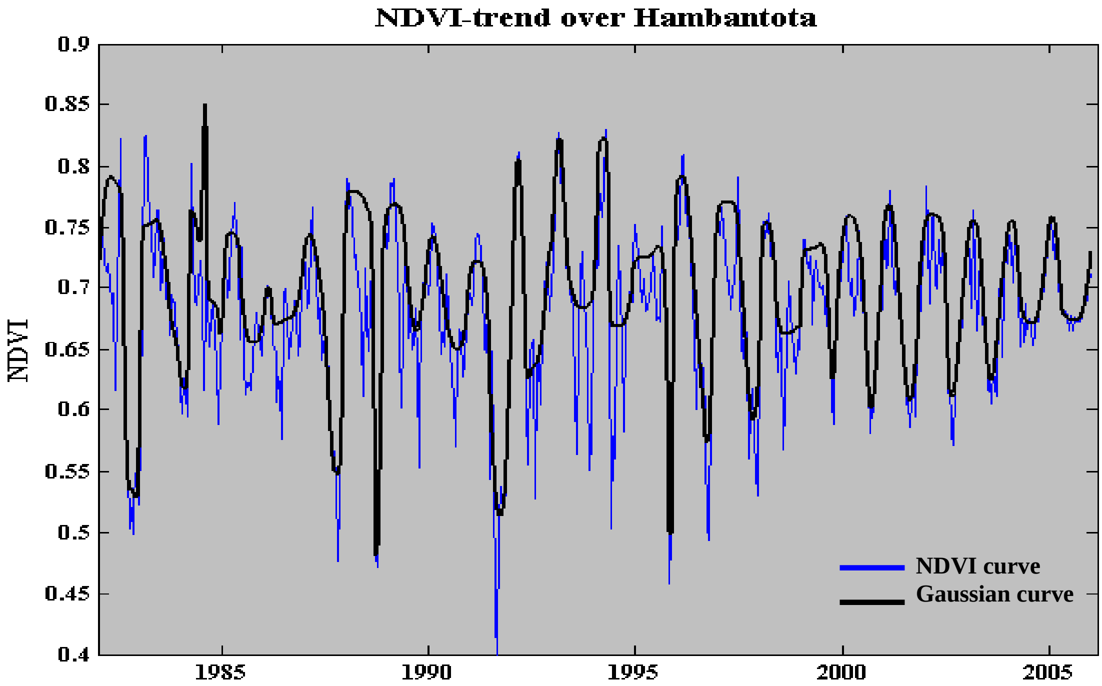

Figure 7 shows the NDVI trend from 1982 to 2006 for Hambantota district with a Gaussian curve to get a more even curve.

Figure 8 to 11 shows a close up on the different years and the dates when the images that were used were registered. All the different images were registered during the first four months of the year. The images that were compared to each other for path 141 had a monthly time difference of two months between the earlier and the later date while the monthly time difference for path 140 was close to three months. When locating the image dates in the seasonal cycle it shows that the images despite months a part is in the same season. Year 2006 has however a bit lower NDVI values but otherwise they are in the same seasonal profile as the other images. In the figures for all the images the dryer period during April to August is more or less pronounce, with the lower NDVI values during June, July and August.

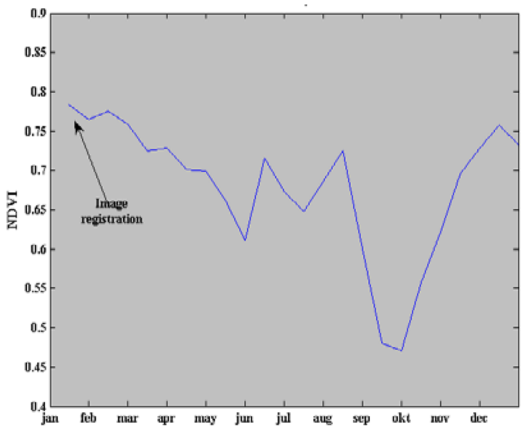

Figure 8 illustrate the NDVI trend for 1988 and the image registration date.

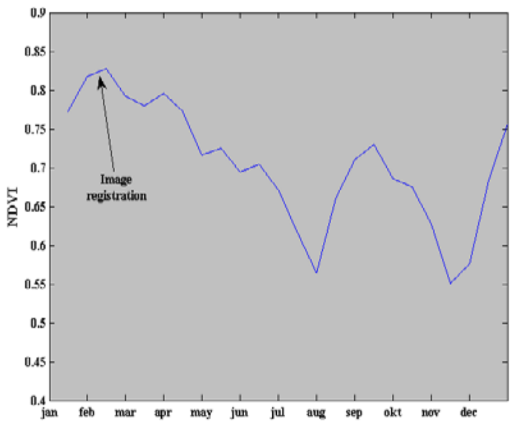

Figure 9 illustrate the NDVI trend for 1993 and the image registration date.

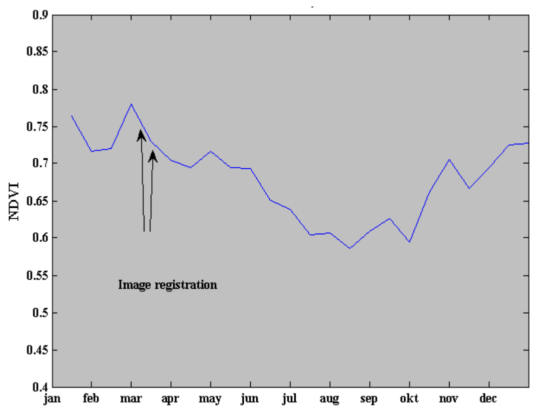

Figure 10 illustrate the NDVI trend for 2001 and the image registration date.

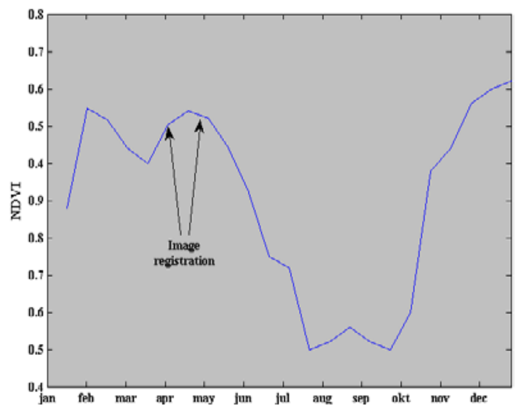

Figure 11 illustrate the NDVI trend for 2006 and the image registration date.

3.3 Change vector analysis

The district is divided between the different images as seen in figure 3, so therefore the result from the CVA is divided in one eastern and one western part. For each part there are two different magnitude and direction images. But to make the result easier to interpret the information from the direction and magnitude images was compressed into one information image by making the direction transparent with magnitude underneath, figures 12 to 15. So where colours are stronger there is a greater magnitude of change. In addition to this a mask were made to take away undesired interference from cloud, cloud shadows and water. These interferences can make the CVA very hard to interpret.

As mentioned before the direction values ranges from 0° to 360°. This scale is a continuous scale where 0° and 360° indicated the same change direction.

When studying the result it is important to take the seasonal difference into consideration. For the agricultural area this difference can be very distinct if the image dates are before and after harvest seen in area 15 in next chapter. Therefore a combination of looking at the raw satellite images, the classifications made and the result of the CVA is important so no miss interpretation occurs.

There area several areas that are interesting where changes have occurred between the earlier dates compared to 2006. These areas will be further discussed in chapter 4.

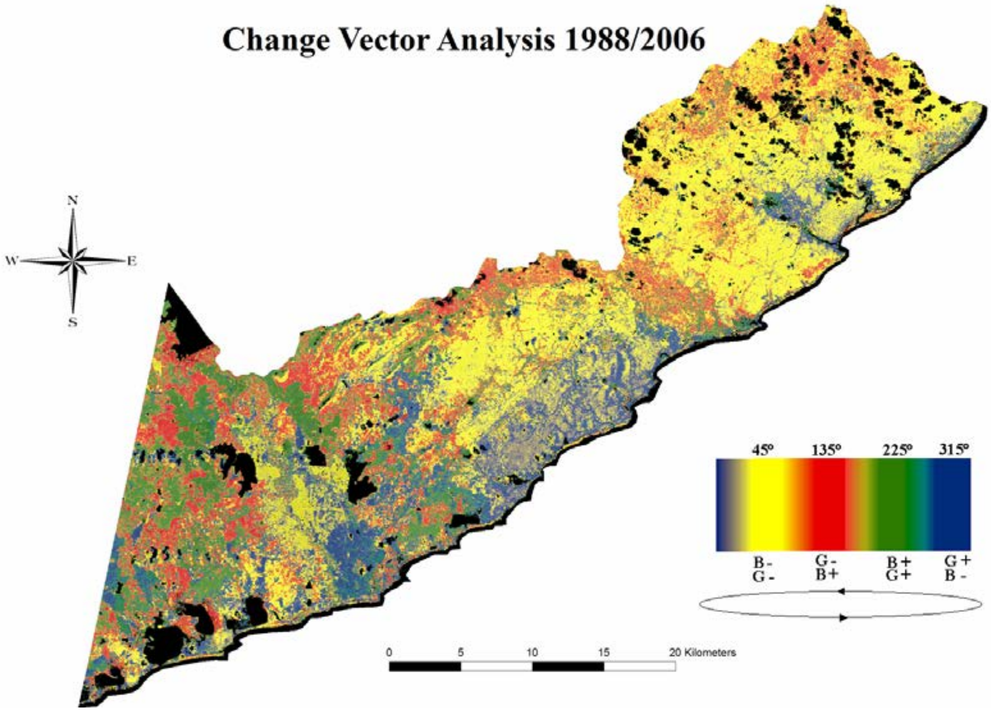

Figure 12. The figure shows the result for the CVA analysis between 1988 and 2006 for the western part of the area.

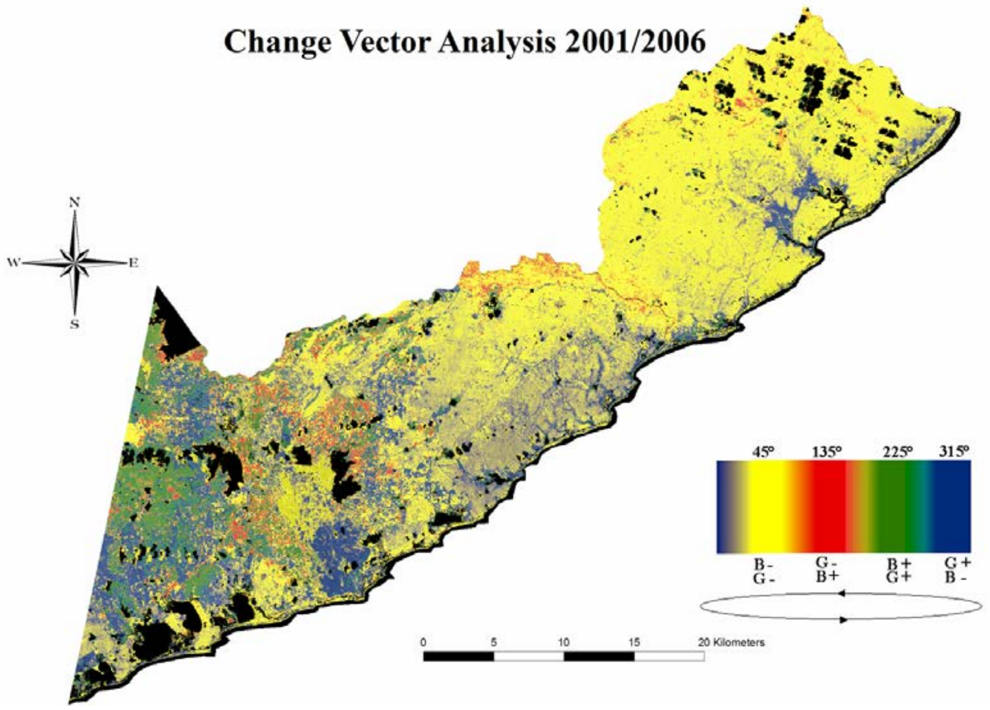

Figure 13. The figure shows the result from the CVA analysis between 2001 and 2006 for the eastern part of the area.

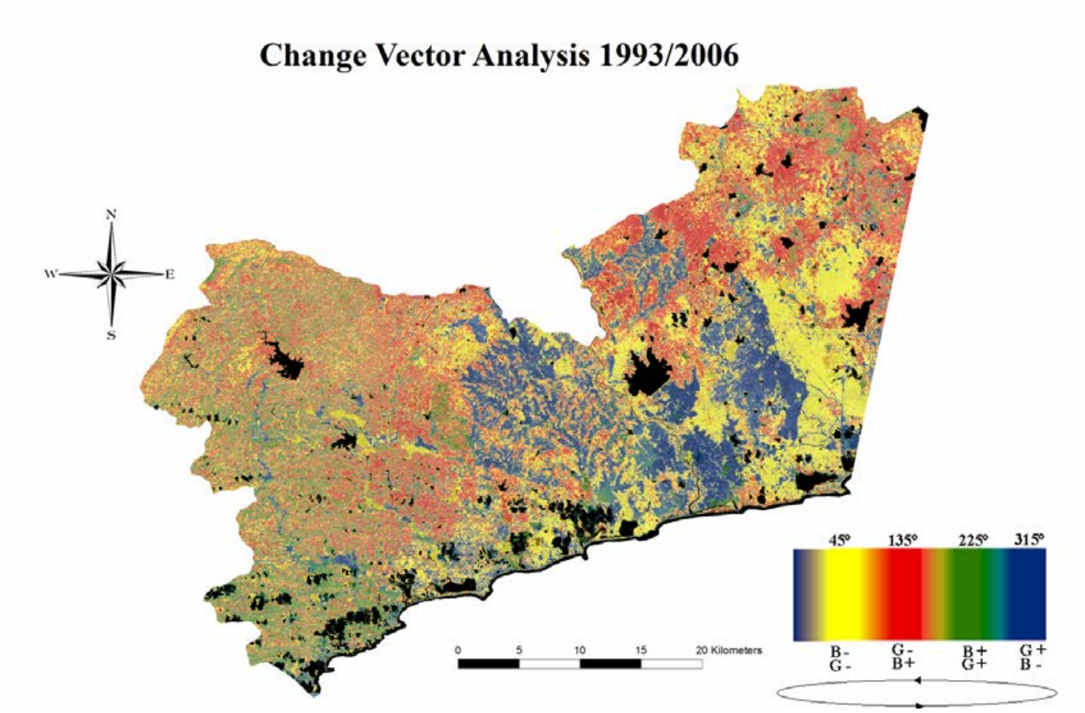

Figure 14. The figure shows the result from the CVA analysis between 1993 and 2006 for the western part of the area.

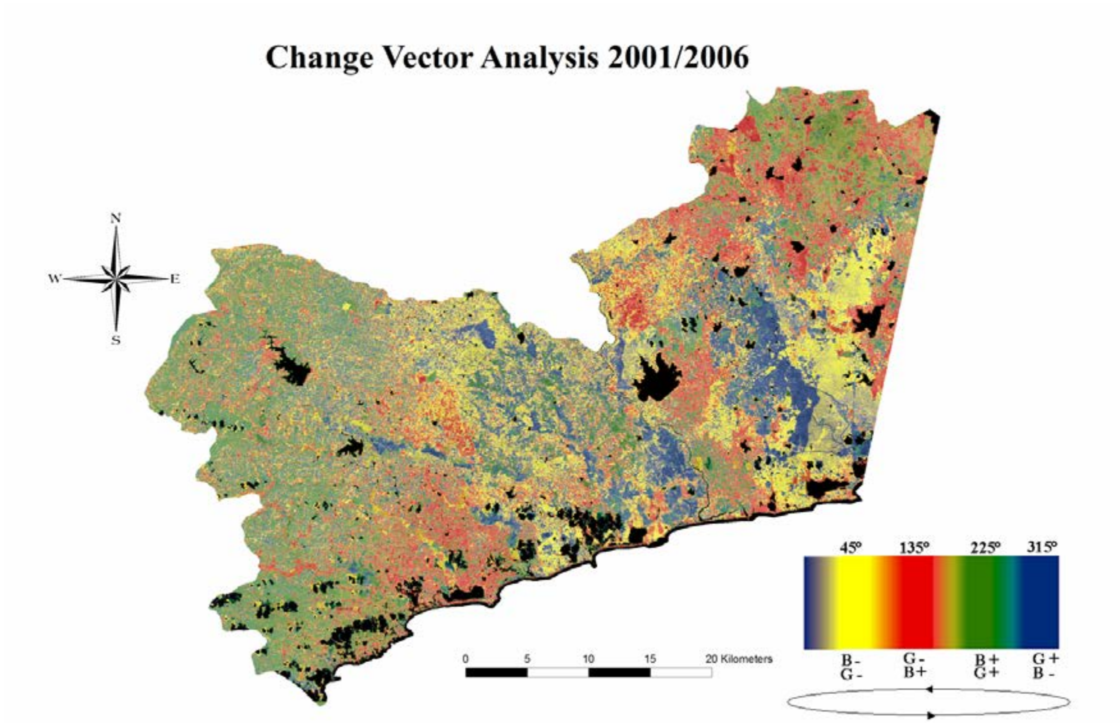

Figure 15. The figure shows the result from the CVA analysis between 2001 and 2006 for the western part of the area.

3.4 Land Cover classification

The result of the 2006 classification is seen in the land cover map, figure 21. The extent of the different land cover classes and their change through time can be seen in the tables 10, 11 and figure 16 to 20.

Table 10 shows the different classes and the extent in % of total area and years for the eastern part of Hambantota.

Year	Water	Rice Paddy cultivation	Banana plantation	Homestead	Scrubland	Bare ground	Forest	Built up area	Cloud & shadows
1988	**6.3**	**9.9**	**-**	**10.8**	**41.4**	**3.9**	**25.9**	**0.006**	**1.8**
2001	**5.8**	**10.5**	**-**	**14.1**	**41.3**	**4.5**	**22.3**	**0.009**	**1.4**
2006	**6.2**	**9.3**	**1.2**	**14.4**	**43.8**	**3.3**	**19.2**	**0.009**	**2.6**

For the eastern part of Hambantota there is an increase in the area with homesteads, since 1988 there has been an increase of 25 %. The total area covered by forest in the region has gradually decreased from 25.9% in 1988 to 19.2% in 2006 which is more than a 30 % decrease. The rice paddy cultivation has increased with 0.6 % between 1988 and 2001 while it has decreased with 1.2 % between 2001 and 2006. For year 2006 the banana plantation class is first detected and occupies 12.9 % of the cultivated area and 1.2 % of the total area. For the bare ground class the difference is that for 2001 the extent is 4.5 % while in 1988 it is 3.9 and 2006 3.3 %. Built up area increase with almost 40% but still has a very small extent of the total area.

Table 11 shows the different classes and the extent in % of total area and years for the western part of Hambantota.

Year	Water	Rice Paddy cultivation	Banana plantation	Homestead	Scrubland	Bare ground	Forest	Built up area	Abandoned Paddy	Cloud & shadows
1993	**2.4**	**15.1**	**-**	**38.1**	**41.2**	**1.9**	**0.9**	**0.17**	**-**	**-**
2001	**2.4**	**15.5**	**-**	**43.0**	**36.3**	**1.5**	**1.1**	**0.17**	**-**	**-**
2006	**4.8**	**15.9**	**2.2**	**43.2**	**30.0**	**0.9**	**0.6**	**0.19**	**0.3**	**1.7**

For the western part of Hambantota a doubling of the water extent has taken place between 2001 and 2006. The area under rice paddy cultivation has increased gradually from 15.1 % in 1993 to 15.9% during 2006. As in the eastern part the banana plantation class is first detected year 2006 were it consists of 2.2 %, which is 11.9 % of the cultivated area. The homestead increased with almost 15 % from 1993 to 2006 between 2001 and 2006 the area is unchanged. The scrubland has decreased with 25 % from 1993 to 2006. The forest extent is varying between the years, between 1993 and 2006 there was a decrease of 30%. The extent of built up area are quite similar in % of total area but the class still increased its extent with almost 20 %.

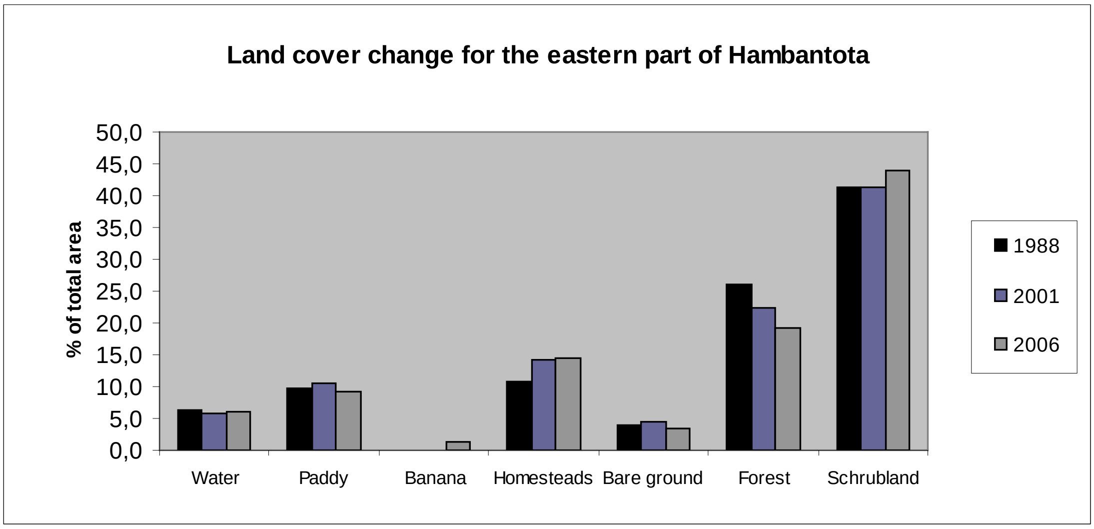

Figure 16 shows the land cover classes' area coverage in % of total area in the eastern part of Hambantota.

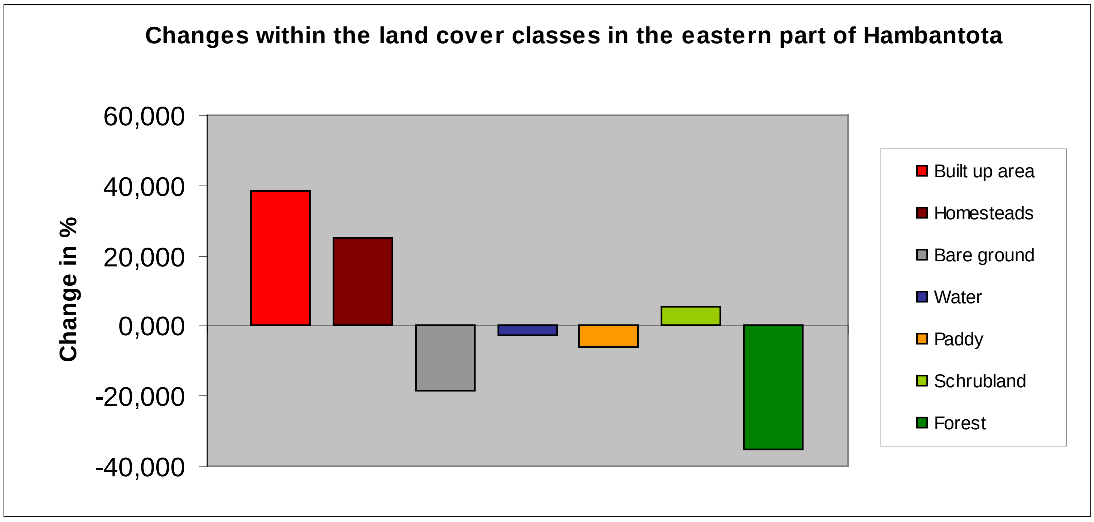

Figure 17 shows the land cover classes' area coverage in % of total area in the eastern part of Hambantota between 1988 and 2006.

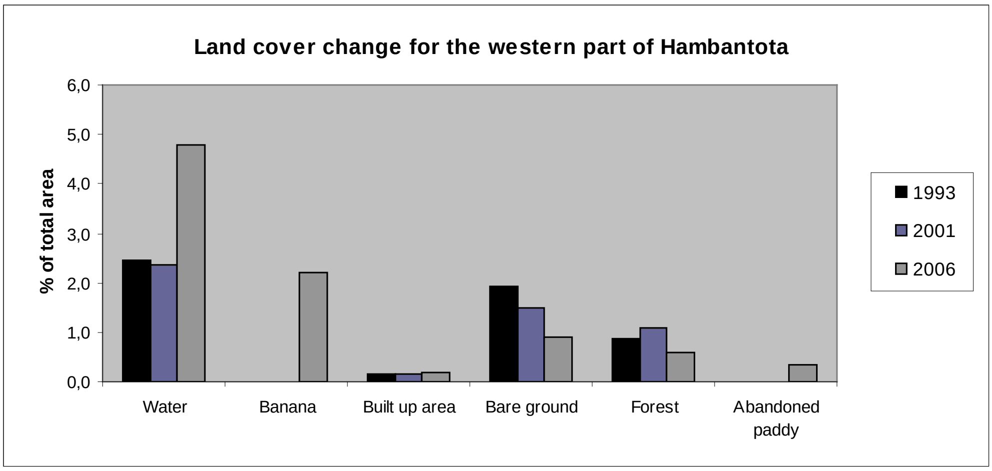

Figure 18 show the land cover classes' area coverage in % of total area in the western part of Hambantota.

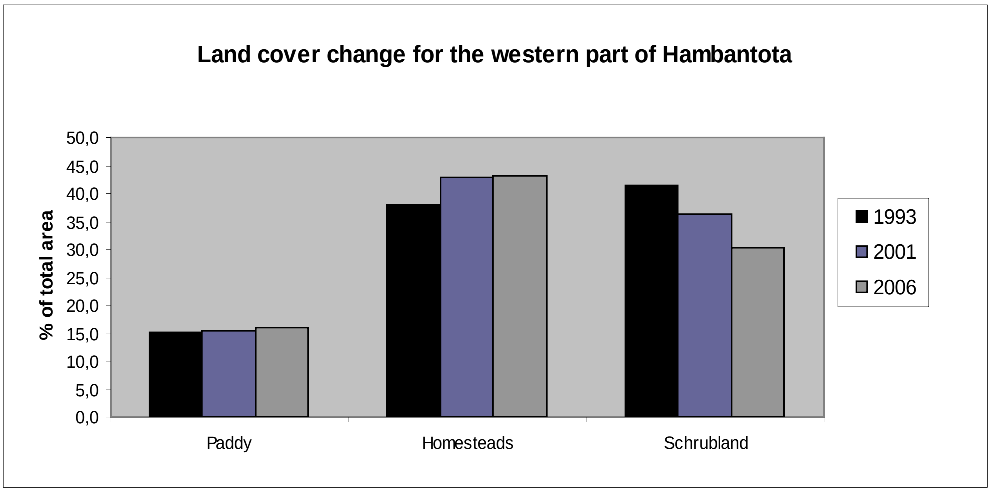

Figure 19 show the land cover classes' area coverage in % of total area in the western part of Hambantota.

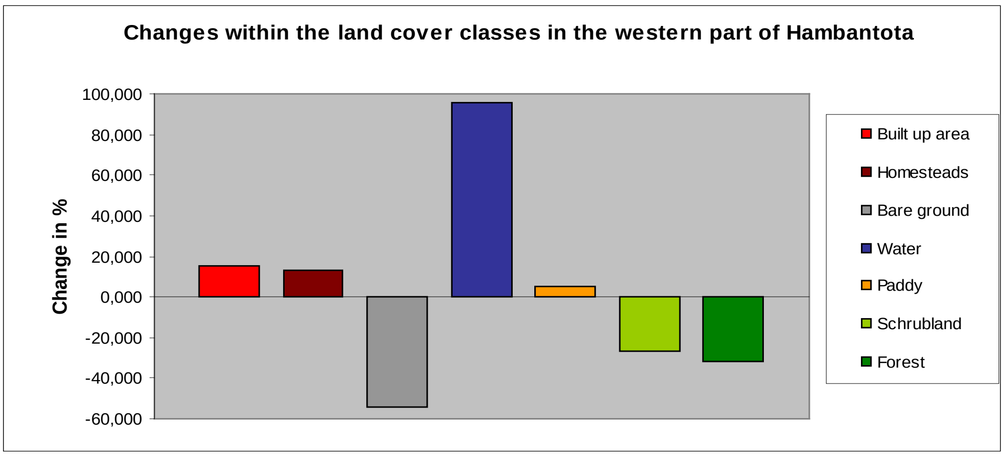

Figure 20 show the changes within the different land cover classes in % in the western part of Hambantota between 1993 and 2006.

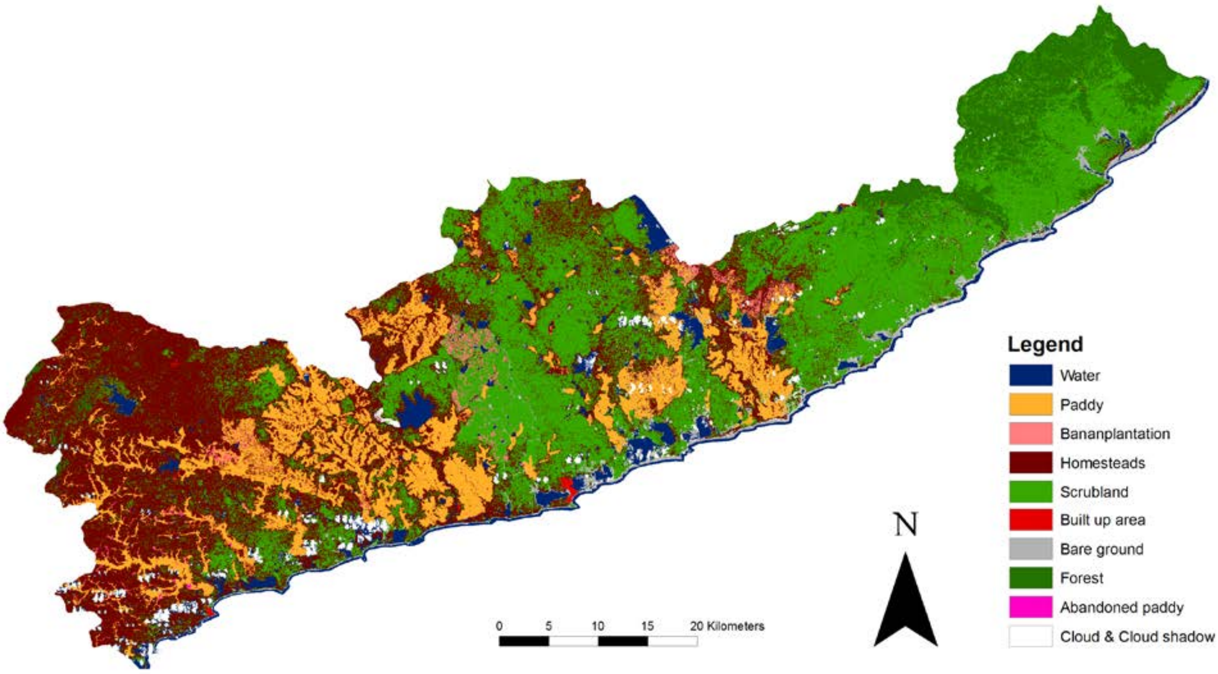

Figure 21 shows the land cover map for 2006. The extent of the district is 456560 west, 659740 south to 578400 east, 727350 north, coordinates in WGS 84 UTM 44N.

3.4.1 Accuracy assessment

Of the two classification methods that were tested on the 2006 images the knowledge based method had a better overall accuracy of 71 % and Kappa value of 0,624 compared to the Supervised Maximum likelihood with 57 % and 0,449. Because of its higher accuracy the knowledge based method was chosen to classify the entire dataset.

In the knowledge based classification the producer's accuracy, user's accuracy and Kappa values were higher for almost all the different land cover classes, table 8. In one land cover class, bare ground, there was a small decrease in the producer's accuracy and in the Kappa value. The classes built up area, banana plantation, rice paddy cultivation and abandoned paddy all were restricted to certain areas in the knowledge based classification. Some of these classes were also the ones that had the highest improvement in accuracy. Built up area improved its Kappa accuracy the most from 0,093 to 1.

The restriction for rice paddy areas reduced the mixture with other land cover classes as seen in table 9 and 10. The mixture that was left was mainly from land cover classes that were possible to exist within the paddy area.

Both the banana and abandoned paddy class improved much but still they had a low accuracy especially in the user's accuracy where a lot of mixture still existed. The accuracy for scrubland and forest which was not restricted in the knowledge based classification also improved in the knowledge based classification. Scrubland has the largest mixture with homestead. This was the case for both of the classifications it was however reduced in the knowledge based classification.

Table 8 consists of the different accuracy variables for the different land cover classes and the two different classification methods.

	Producer's Maximum	Producer's Knowledge	User's Maximum	User's Knowledge	Kappa Maximum	Kappa Knowledge
Water	*90%*	*91%*	75%	*89%*	0,893	0,909
Rice Paddy	*75%*	*80%*	63%	*83%*	0,668	0,738
Banana	*25%*	*55%*	5%	30%	0,168	0,499
Homestead	*58%*	*68%*	77%	76%	0,411	0,542
Scrubland	*45%*	*63%*	43%	67%	0,292	0,528
Built up area	*11%*	*100%*	33%	56%	0,093	1
Bare ground	*57%*	*50%*	100%	100%	0,565	0,527
Forest	*52%*	*81%*	54%	54%	0,499	0,804
Abandoned paddy	*20%*	*50%*	17%	33%	0,192	0,495

Table 9. The confusion matrix for the Supervised Maximum likelihood classification method with the producer's accuracy and user's accuracy for the different land covers classes.

Supervised Maximum likelihood	**Water**	**Rice Paddy**	**Banana**	**Homestead**	**Scrubland**	**Built up area**	**Bare ground**	**Forest**	**Abandoned paddy**	*Number of points*	*Producer's accuracy*
Water	**27**				**1**				**2**	*28*	*90%*
Rice Paddy	**2**	**90**	**11**	**5**	**6**	**3**		**1**	**2**	*122*	*75%*
Banana		**1**	**3**	**7**	**1**					*12*	*25%*
Homestead		**14**	**23**	**130**	**45**	**3**		**7**	**1**	*223*	*58%*
Scrubland	**5**	**27**	**15**	**15**	**55**			**3**		*123*	*45%*
Built up area		**7**	**2**	**8**	**8**	**3**				*28*	*11%*
Bare ground	**1**		**1**	**1**	**3**		**8**			*14*	*57%*
Forest	**1**	**2**			**9**			**13**		*25*	*52%*
Abandoned paddy		**2**	**2**						**1**	*5*	*20%*
Number of points	*36*	*143*	*57*	*169*	*128*	*9*	*8*	*24*	*6*	*580*	
User's accuracy	*75%*	*63%*	*5%*	*77%*	*43%*	*33%*	*100%*	*54%*	*17%*		

Table 10. The confusion matrix for the Knowledge based classification method with the producer's accuracy and user's accuracy for the different land cover classes.

Knowledge based Classification	**Water**	**Rice Paddy**	**Banana**	**Homestead**	**Scrubland**	**Built up area**	**Bare ground**	**Forest**	**Abandoned paddy**	*Number of points*	*Producer's accuracy*
Water	**32**		**0**	**0**	**1**				**2**	*33*	*91%*
Rice Paddy		**118**	**19**	**6**	**2**				**2**	*145*	*80%*
Banana		**5**	**17**	**5**	**4**					*31*	*55%*
Homestead	**2**	**9**	**13**	**129**	**28**	**3**		**7**		*191*	*68%*
Scrubland	**2**	**9**	**7**	**28**	**86**			**4**		*136*	*63%*
Built up area						**5**				*5*	*100%*
Bare ground		**2**		**1**	**3**	**1**	**8**			*15*	*50%*
Forest					**3**			**13**		*16*	*81%*
Abandoned paddy			**1**		**1**				**2**	*4*	*50%*
Number of points	*36*	*143*	*57*	*169*	*128*	*9*	*8*	*24*	*6*	*580*	
User's accuracy	*89%*	*83%*	*30%*	*76%*	*67%*	*56%*	*100%*	*54%*	*33%*		

4. Analysis of detected changes

This chapter will discuss and highlight some of the more interesting results where areas of change have been observed. To make this process as accurate and reliable as possible the results from the classifications, change vector analysis, seasonal fitting and field data will be combined to explain some of the changes that were found. A combination of change detection methods is recognized by Lu et al (2004) to be an effective way to improve the process. In the analysis of the changes it is important to take all the result into account so no miss interpretations of the results are made.

For the two land cover classes abandoned paddy and banana plantation the change is only discussed between the earlier images from 1993 and 1988 compared to 2006. The extent of these two classes during 2001 is unknown and with no field data to support the classification they were excluded for this year. During the time when the two earlier images were registered it is known through the interviews in the divisional secretariat that these classes did not exist. In the change detection analysis the 2001 images are foremost used in the identification of land cover changes due to the Tsunami.

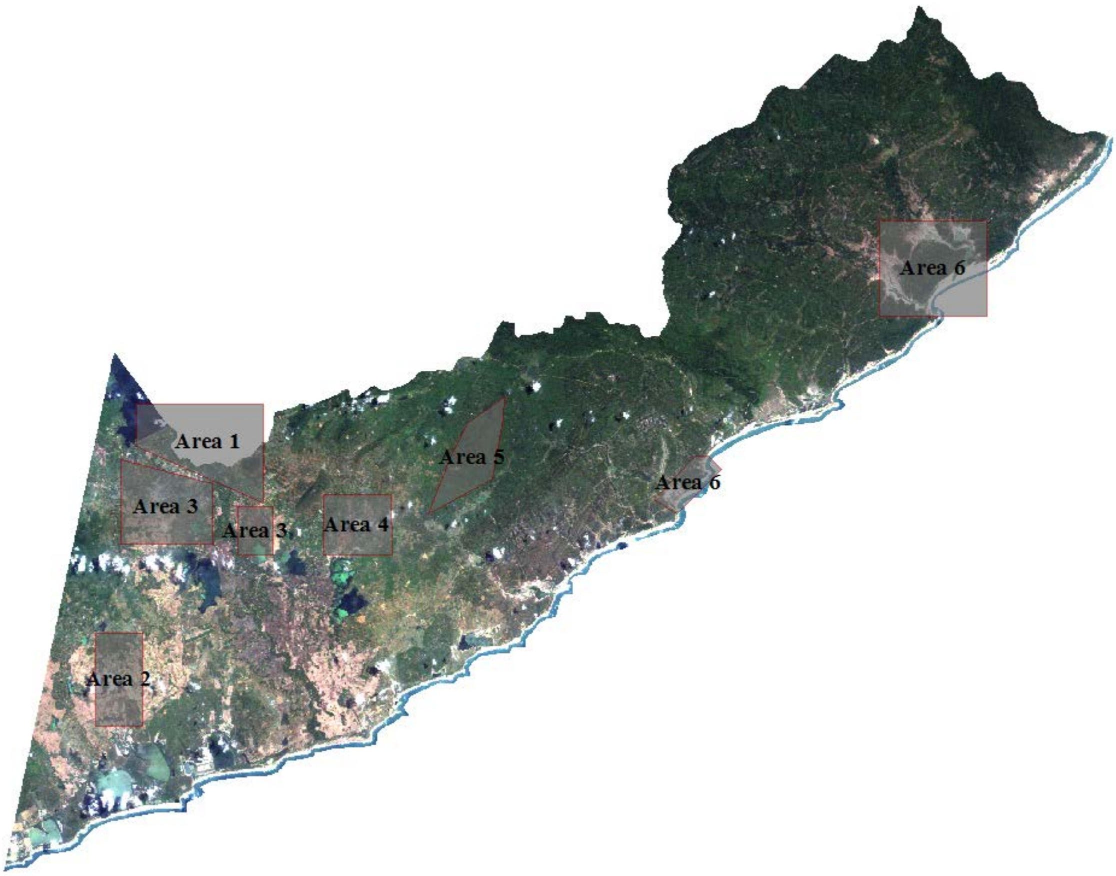

Figure 22 shows the different areas that are highlighted in section 4.1 in the eastern area. The image covers area one to six.

4.1 Eastern part of Hambantota

The different areas are presented in figure 22, for more information about CVA see figure12 and 13.

Area 1, just south of the Lunugamvehera tank there is a belt along the border of the district where a clear change has occurred between 1988 and 2006. This area is a part of a large irrigation scheme which is supported of the Lunugamvehera tank. There are two different zones of change, one where a large increase in greenness and decrease in brightness have been registered and one where there is a clear increase in greenness. In the 2006 land cover map this area is classified as a mixture of rice paddy fields, homesteads and the larger part as banana plantation. During the field work the area was visited and it became evident that large parts of the paddy fields consisted of banana plantations. The fact that this was a change that had taken place became further supported during the interview made in the divisional secretariat. The interviewee said that this area had started growing bananas during the early nineties and that it now could cover as much as 75 % of the paddy fields. The reason for this was that the tank could not support the whole area with enough water for rice cultivation as planned. The banana plant needs less water so the farmers were allowed to change which is not always allowed. This increase in banana cultivation have been seen in several areas but in this region the banana cultivation has become more dominating than in other regions.

Area 2 shows an area where increases in greenness and decreases in brightness have occurred in the paddy fields between 1988 and 2006. The greening of this area is explained when comparing this area of change with the land cover map. It shows that some part of the paddy fields has turned into homesteads on both sides of the paddy fields. It also becomes clear that a change has occurred, when looking only at the satellite images where the homesteads are quite easily separated from the paddy fields.

Area 3 shows an increase in greenness and decrease in brightness between 1988 and 2006. However the change does not have a very large magnitude in parts of the area. Comparing the classified data it shows that the area were classified as scrubland in 1988 and turned into homesteads in the 2006 land cover map. The reason that the change did not have a very large magnitude is that the homesteads are quite dry here and not as green as in many other places, which makes it harder to detect

Area 4 is divided between two different change directions between 1988 and 2006. One area where the change is similar to the registered change in area 3 with an increase in greenness and a decrease in brightness and a second where the change is the opposite with a decrease in greenness and minor changes in brightness. The classifications show that in 1988 the area mostly consisted of scrubland while in 2006 it has turned into banana. In the satellite images it is also clear that in the 1988 image this area is very dry which makes the greening trend more apparent. These two results match each other and are further supported by the field work. The second change direction is registered where there are rice paddy cultivations in 2006. Much of the change is because of new fields but some of them were there in 1988 as well. The new fields explain the decrease in vegetation, and seasonal differences are a likely explanation for the other change.

Area 5 in the middle of the eastern part a large area that consists of natural vegetation shows a strong decrease in the greenness and a minor change in the brightness indices. Similar change can be observed both between 2001 and 1988 compared to 2006. This result supports the NDVI trend for 2006 with the lower values then the other years.

Area 6 show parts of the coastal areas in the eastern part with a decrease in greenness and an increase in brightness over a part of the coast and in land between 2001 and 2006. Along the coast the change is due to a wider beach in 2001 but further in land the change is due to other factors. In the classifications there is more bare ground instead of scrubland in 2006. This area is inside Yala national park and was visited in the field where the vegetation cover showed clear signs of damage. Another area further north was also visited where the same damage to the vegetation had occurred. It also had a similar result from the CVA which indicates that this area also was affected by the Tsunami. During both of these visits there was a guide following, the guide described both areas as Tsunami damaged areas. When comparing the affected areas with an elevation model it seems to be areas with lower elevation where this kind of change has been registered. The fact that the areas have a low elevation which would make them more likely to be damaged by the Tsunami also supports that it was affected by the Tsunami. There are other areas along the coast that show signs of a similar decrease in vegetation, however these areas was not possible to reach in the field.

Figure 23 shows the different areas that are highlighted in section 4.2 in the western area. The image covers area seven to fourteen.

4.2 Western part of Hambantota

The different areas are presented in figure 23, for more information about CVA see figure14 and 15.

Area 7 is located just north of Hambantota town. Here a clear decrease in greenness and an increase in brightness can be observed. The change has taken place between 2001 and 2006 and is seen clearly in the satellite images. In the classifications the result is harder to interpret, the area is a mixture of scrubland and bare ground in 2006 while it is only scrubland in 2001. What is clear though is that the vegetation in the area has significantly decreased. The area was visited in the field and it was found that the area consisted of newly built houses scattered in an area dominated by scrubland. During the interview in the divisional secretariat it became clear that these houses were built in 2005 for people that lost theirs in the Tsunami. In 2006 when the satellite image is registered the area was newly developed with no vegetation which gives a very high brightness and low greenness values. The site still had a very low vegetation cover during the visit in field. The land cover change in this location is an indirect result of the Tsunami. By destroying housing in coastal areas new grounds have been developed to support new houses. This is done at the cost of scrubland areas.

Area 8 is another site that had a similar change as **area 7** with a very strong magnitude of decrease in greenness and various changes in brightness. In the satellite image from 2006 this site looks like it has been cleared from much of the vegetation. The land cover map from the different time periods shows that this area consists of scrubland. The land cover class scrubland is a class with a lot of variations stretching from very dry and sparse to wetter areas which are closer to forest. This means that the change that has occurred can be very significant even if it is the same land cover class between the years. This location was visited during the field work and in some areas there were small scale agricultural production. But these areas were very hard to separate from scrubland with low vegetation. Where there was cultivation going on it mostly consisted of low growing crops similar to bushes which made it very hard to see to what extent these existed.

Area 9 located west of Lunugamvehera several smaller patches can be observed where a decrease in greenness and increase in brightness and the opposite have been registered. In all the classifications this area is made up by scrubland. This is also an indication of the agricultural production that exists in the scrublands as mentioned for area 8. In this location the major changes was a decrease in the vegetation and an increase in brightness. The reason that there have been changes in both directions should be the result of new areas that are cleared while other is abandoned. These cycles are natural when conducting chena cultivation and are the most probable explanation for the change in this area.

Area 10 is located close to the south western border of Hambantota. During a field visit in this site there were several small and larger patches of abandoned paddy fields that were observed. In the CVA analysis there is a clear increase in greenness with various changes in brightness. The explanation for the increase in this area is that these fields were newly harvested in 1993 which result in a very low greenness value. Abandoned paddy has a spectral signature similar to Scrubland with quite high greenness values. The greenness change between the dates in this area should be an increase which the result in the CVA was. The 2006 land cover map classification classifies this area as abandoned paddy and as rice paddy during 1993. The fields were also visited and the fact that the fields were abandoned was confirmed. The farmers in the area said that the main part of the fields had been abandoned for two years. The reason to why the fields had been abandoned was due to water shortage. The fields were supported by a local tank which had broken down and it had not been fixed. The farmers did not give any answer to why it had not been fixed. There was also a smaller area that had been abandoned for a longer time period, approximately ten year. This field was located next to the larger area and was not irrigated. The farmer to the field also said that they did not grow any crop on the paddy field because a lack of water. The reason for it was however different, the farmer said that irregularity in the raining season led to water shortage during vital water demanding periods. The crop could be destroyed during this period and it was considered that it would be a too high economical risk to cultivate the paddy field.

Area 11 show an area where you can see changes around the water bodies between 2006 compared to 1993 and 2001. In this site strong increases have been detected in the brightness values and strong decreases in the greenness around the water body. This should indicate that 1993 and 2001 were drier years compared to

2006, and the increase of the water extent seen in table 11 could to some degree be explained by this. This is however not shown in the NDVI values from 2006, figure 11. The 2006 image had lower values then the other years during image registration.

Area 12 is a site where a lot of different changes have taken place between 1993 and 2006. The dominating change is an increase in greenness with various degree of change in brightness and magnitude. This change direction also coincides with the results from the classification where much of the area has turned into banana plantation from previous scrubland. This area is located in Sooriyawewa division, during the divisional interview it was told that in this area there where extensive banana plantation. The reason for this was simple because it was allowed for the farmers to grow banana. The farmers usually increase there income substantially if they grow banana instead of rice.

Area 13 shows an area where there have been several new water bodies in 2006 since 2001. This is a contributing factor for the increase in the water land cover class. These newly created water bodies are most likely to be tanks. This change has taken place in several areas but is more extensive around this site. In the CVA analysis there are decreases in both greenness and brightness with a high magnitude for these places. The change in brightness is due to the low reflectance values that water has. If you put this site in a larger perspective this site is located near area 12. Area 12 have seen a great loss in its scrubland vegetation while an increase in the banana land cover class has been registered in the 2006 land cover map, figure 21.

Area 14 in the middle of the western part close to the district border there has been a strong decrease in greenness and an increase in brightness. This change has taken place between 2001 and 2006. The site consists of scrubland according to the 2001 land cover map while it is classified as rice paddy fields in 2006. This change is supported by the CVA direction registered, the decrease in greenness is due to newly harvested paddy rice fields during image registration. The change in this location explains part of the increase in the rice paddy class, table 11.

Area 15 illustrates the seasonal difference in the paddy fields that can be registered. In this area there is a strong decrease registered in both CVA variables. This area is more to show how a great change can be registered in the CVA analyse while no change has taken place and it is therefore important to compare the result from the CVA analyse with other results and data.

5. Discussion

5.1 Data and Method discussion

5.1.1 Field study

The field study in Sri Lanka consisted in two major parts. One part was the gathering of information by conducting interviews and the other to collect GPS control points to use in the classification process. During the interviews a semi-structured interviewing technique was used, where you are quite free to take the interview in any direction. This technique was found to be very suitable because you can be prepared with different topics that are going to be discussed but still be able to ask about other information that might come up during the interviews that you had not thought of before. The purpose of the interviews was to collect additional information to support the change vector analysis and classification done over the region. The interviews that were made were very important to get a deeper understanding about the area and that changes that had taken place. To get information that was comparable between the different divisions it was important to have some kind of structure in the interviews and not only an open discussion. The themes that were discussed were this structure and each theme consisted in several questions which made it possible to compare the information afterwards.

The themes that were brought up during the interviews can be divided into tow categories. The first two concentrated on what kind of land covers the division consisted of and how they had changed through time. These two topics were where the focus laid during the interviews and where most time was spent. The following topics where constructed to try to find out more about the reasons why any possible change had occurred.

The information that was gathered from the interviewees could be of varying quality depending on the person interviewed. The person that was interviewed was usually selected by the assistant director of the divisional secretariat and sometimes the person lacked the information to be able to answer the questions. Typically the interviewed was the land use planning assistant but it could be that the person was not at the office that day and then someone else was selected to be interviewed.

The collection of GPS points was the second part of the field study. These points were used to geo reference the images, as training areas in the classification process and as input to the confusion matrix for the accuracy assessment. In total 30 points was collected to geo reference the 2001 images and 576 points to use in the accuracy assessment. The distribution over the different land cover classes can be seen in table 6. The land cover classes that had larger number of validation points than others were rice paddy cultivation, homestead and scrubland. These three classes were by fare the most dominating classes in the district, which had a clear effect in the points that were collected. The goal when selecting driving routes was to get an even number of validation points distributed over the district and the land cover classes. But still it was hard to get a more even coverage between the classes. There was also a problem finding suitable validation points for the banana class. The extent of the banana cultivation was usually very small and not suitable to take validation points in. For the abandoned paddy class the problem was that there were not that many areas that were known to be abandoned and that was reachable. To find these areas you would have to search for them which was very time consuming.

5.1.2 Data

The selection of images was foremost governed by the growing pattern of rice. The dates that were selected for the images worked well to some degree. A problem was that the growing cycle varied more between different places in Hambantota than understood when selecting the images. This was something that became very clear during the field study when one area was not harvested while in another area the farmers were preparing the field for sowing.

During the preparation work the fields are ploughed which gives a greenness value of zero, this makes it much easier to differentiate between rice and for example banana. It was possible to separate them when the rice cultivation was in a later growing stage with a higher greenness value but it was more difficult to do so. The site mentioned for **area 1** south of Lunugamvehera was located in the area where an overlap existed between the two images that covered the district, so the two images from 2006 both covered the area. There was almost a month apart between these two images and in the eastern part which was registered later there were preparation work in the field during image registration. For this area it was much easier to separate between banana and rice cultivations and the result became more accurate when comparing the two classifications.

5.1.3 Pre processing

The pre-processing method that was used is a well known algorithm, calculating the at-reflectance for radiometric correction of the images has been used in many studies and in different applications. However after calibrating the satellite data to at-reflectance there was still a lot of interference in some of the images, which mainly originated from haze in these images. To reduce this interference an additional algorithm called histogram adjustment was applied on the images. After the adjustment a lot of the variations between the different satellite images were removed. Still there were some interference left but this additional calibration took away much of this that was unrelated to ground reflection and the made the histograms more even and improved there comparability much.

5.1.4 Seasonal fitting

A seasonal fitting is important to investigate to be able to see in what seasonal stage the natural vegetation is in and if the years that are studied have any anomalies in their NDVI values through out the year. In this study the focus and questions was foremost directed against non natural land covers like paddy fields. These land covers and especially the irrigated areas only follow the natural cycle to some extent. When investigating controlled cultivations the natural season is of less importance.

One aim was also to investigate if there had been any effects from the Tsunami on the land covers, much of the effected areas consisted of natural vegetation so for this aim the stage of the natural vegetation was of greater importance.

In NDVI values from 2006 was lower then the other years. This could be a result of a drier year. It can also be a result of a different data source. The NDVI values from the NOAA data set did not cover 2006 therefore another data set from MODIS was used for this year. This should not affect the result but it might be part of the explanation for the lower NDVI values.

5.1.5 Change Vector Analyses

Change detection techniques all have advantages and disadvantages, the disadvantage with the CVA is the fact that you do not get any kind of information about the state of a given pixel (Johnsson, 1998). The CVA result consists of a very detailed information of what kind of change that has occurred which is one of its big advantages. The problem with no state information is solved by using it in a combination with the classifications that was made in the study. Comparing the CVA and the classification between the dates gives a very good understanding of the result. The CVA direction and magnitude can be used to see if the change that the area have been subjected to according to the classifications can be explained and vice versa. This comparison with field data and visually interpretation of the images is what chapter four tried to do where some areas were highlighted.

One major disadvantage with the differences in the growing cycle between different places in Hambantota was that a change that had occurred did not give the same change direction (in the CVA analysis). If a rice field had been abandoned the change direction would have been more or less the same all over the district if the rice would have been in the same growing stage. This direction could then have been selected and separated from other areas as possible abandoned areas.

5.1.6 Land Cover Classification

To be able to make an accurate classification for this study area a visual classification was thought to be too coarse. In this region the changes that this study intended to capture with in the cultivation would be too small to locate by a strictly visual interpretation. The result of a visual interpretation would be that a lot of variation would be missed and with the Supervised Maximum likelihood algorithm the accuracy proved to be to low. Therefore a compromise were made with a knowledge based version of a Supervised Maximum likelihood with a prior probability function, visual analysis and the usage of the result from the CVA to locate areas of change. In the accuracy assessment the overall accuracy was increased from 57% for the Supervised Maximum likelihood to 71% for the Knowledge based classification while the kappa value increased from 0,449 to 0,624. Both of the accuracy methods indicate a strong increase in accuracy for the knowledge based classification method. The accuracy increased in almost all the different land cover classes with the knowledge based classification, table 8. This increase shows that the modified method was much better than the ordinary Maximum likelihood and that it was motivated to use this method to analyse the remaining images. To minimize differences that originate from the selection of the training areas both methods used the same training areas. If it was certain that the land cover was the same in the different images and dates the same approach was applied in the final knowledge based classification. This was not always the case so there were some differences in the distribution of the training areas.

The knowledge based classification that was made in this study does not require much more knowledge about the area than an ordinary method does. The areas that were digitized were constructed with the help from existing land cover maps and by visually selecting areas. The information from the CVA was extracted quite easily and served as great extra information. For study areas where it is hard to separate the different land cover classes this method could be a suitable extension of the Maximum likelihood algorithm. When it is possible to give the classes spatial restrictions and also a kind of temporal restriction with CVA analyse it is possible to improve the classifications a great deal. An example of this is the banana cultivation. For the areas where this land cover class could exist there were two restrictions. The first was that it could only exist in the digitized paddy area and the second was that there had to been a change in the CVA analyse. One of the results from the last restriction was that the homesteads that was inside the paddy area was excluded because no change had occurred.

The same conditions that would have improved the CVA would also improve the knowledge based classification. A more unified growing pattern of the different crops covering the district would have improved the quality. Then one CVA direction could have been more characteristic for one change that had taken place between the dates. For a specific class one direction interval could have been identified and used as a restriction in the classification. This could have improved both the classification and the analyse as a whole but in reality this unified crop state is probably very rare.

The biggest weakness with this method is the same as its strength, the fact that certain land cover classes are restricted to certain areas. If locations that contain these classes are missed in the digitizing process it results in pixels that are misclassified and an inaccurate result. The method is also very time consuming compared to an ordinary approach. The knowledge based method is to a great degree an iterative approach where a lot of time is spent on testing different information inputs before a final classification can be made.

5.2 Result discussion

An interesting fact with the classification result, figure 21, is that there are apparent similarities with the agro ecological regions in figure 2. The drier eastern part consists of more natural vegetation than the western part which mostly consists of homesteads and paddy fields. The western part is more suitable for cultivation and homesteads than in the hotter drier east.

For the land cover type's banana plantation, rice paddy cultivation and abandoned paddy which all had distribution restrictions the accuracy improved much. The mixture that still existed within these classes was kept to the possible classes for the digitized paddy area. Even if the accuracy for the banana plantation class increased it had a low accuracy which can be due to many factors. Part of the explanation is that in the western part the difference in the growing season between banana and rice was not as pronounce as in the eastern part. The seasonal difference was important to see to be able to separate the banana plantation from rice cultivation.

Another factor that probably was the main contributor for the low accuracy is the extent of the banana plantation. Banana plantations were grown in large scale in the two regions Lunugamvehera and Sooriyawewa. Outside these two regions banana plantations were grown in much smaller scale, the extent usually was usually around 100*100 m^2. To be able to register a validation points the land cover class must have an extent of 100*100 meters. Some of the validation points in the banana land cover class were registered close to this lower limit. Even if the validation points were in these smaller patches it was decided that these points should be used to be able to get a larger coverage over the area.

A possible explanation or a contributing factor can also be that the banana plant is grown in cycles and is replaced by rice after about five years. During the field study this fact was considered and it was estimated how old the plant was to be able to take the time difference between the field data and the satellite data and into account. In this process mistakes could have been done which led to errors in the classification.

The abandoned paddy had almost the same accuracy as the banana plantation class. The most probable cause for the low accuracy is that there were a very small number of points in this class, in total only 6 validation points in the class. The extent of this class is very small so to be able to get any training areas and validation points in the class, areas where interviewees had reported that there could be any abandoned paddy were visited. This was very time consuming and was not possible to do many times. One explanation for the low accuracy is that two of the validation points are in an area where the paddy fields have been abandoned because of high levels of salinity. This area consists of some kind of wetland and is classified as water in 2006 which explains the somewhat strange mixture with water in the accuracy assessment. This points out the big disadvantage with the knowledge based method, in this case areas that are not visually digitized and removed as possible areas for the class.

The land cover class scrubland covers a large span of vegetation, from quite dry and sparse to wetter and denser vegetation. In the satellite images it was possible to separate these two sub classes. During the field work these two sub classes was used when collecting validation points but it was not possible to see any similarities with the differences in the satellite images. When collecting the validation points it was hard to separate and see a clear distinction between the two sub classes and to be consequent. The validation points from these two subclasses were therefore too bad to use and was combined to one land cover class. The result from the classification implied that the extent of the sparse scrubland increased from 1988 to 2006 in the eastern part. These results also coincide with the result from the CVA where there was a decrease in vegetation, chapter 4 **area 5**. This result could also be seen in the 2006 NDVI analyse, figure 11, which had lower values than other years. This could simply be caused by a drier year in 2006, another cause could be an increase in agricultural production in these areas. In **area 8** this change is seen, the area is classified as scrubland but a large decrease in vegetation has taken place between the years. During the field visit there was also some agricultural production in the area. Overall there was an increase in the extent of this land cover class. The other land cover class that consisted in natural vegetation was forest. The largest extent of forest is found in the eastern part. According to the classification the extent has decreased in both the western and eastern part of Hambantota. It is hard to be really sure about this because these areas where the larger forests exist are very remote and hard to reach. It is possible that some of the decrease is due to a dryer year in 2006.

The land cover class that had an areal increase in both parts of Hambantota was built up area. In the eastern part the largest increase had taken place but still the areal extent is quite modest. The eastern region has increased in population with a large colonisation of more remote areas. This is a probable cause for the large increase in the built up area.

The cloud and cloud shadow class is something that serves as an error source. It is almost impossible to find satellite images that do not contain any clouds. The satellite image that had most clouds was the one covering eastern part of Hambantota in 2006. The area that is covered by clouds is part of some other land cover class and it is hard to see which land cover class that is affected most of this. It will always affect the result negative making the areal calculations some what unsure.

One of the aims in this study was to investigate possible land cover changes due to the Tsunami in December 2004. In **area 6** in the eastern part of Hambantota there are several areas that clearly have been directly affected by the Tsunami. These areas all consist of natural vegetation. In this study there has not been any evidence that any other than natural vegetation has been directly affected and shown long term damage. The interviews that were conducted also resulted in the same conclusions. A simple reason to this is that the amount of agricultural area close to the sea is very limited. An indirect affect has been seen in **area 7** where newly houses have been built to house people that have lost there homes in the Tsunami. There has been a large destruction in the residential areas in Hambantota. This is however something that has taken place in a small scale which is not visible in the satellite images.

6. Conclusion

This study has come to the following conclusions and answers to the questions asked in the aim in section 1.3.

- The results from the methodology that was developed in this study has shown reasonable accuracy. The knowledge based classification showed an increase in accuracy compared to the Maximum likelihood algorithm, and together with the CVA and interviews it gave a good picture of the change that has taken place.
- The dominating large scale land cover change that has occurred in Hambantota is a decrease in natural vegetation and an increase in cultivated and residential areas.
- The study found that there are several areas where paddy fields have been abandoned. The areas were only found in the western part in Hambantota.
- The cultivation has been more diversified in some areas, an increase of banana plantation has taken place since the late eighties and early nineties.
- There are several causes that can be part of the explanation to the observed land cover changes. The changes within the cultivated area are foremost economical driven, to increase the income the farmers have changed from growing rice to banana. The large scale change that has taken place is mainly due to an increase in population in the area. In Hambantota district a colonization process has taken place where new areas have been developed and extensive irrigation projects have taken place.
- Land cover changes that have been observed that were caused by the Tsunami in December 2004 can be divided into indirect and direct effects. Indirect effects have been newly built housing areas for displaced people that lived near the coast before the Tsunami. Direct effects have been damaged coastal areas in Yala national park.

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