Detection of Mangrove Changes Using Multi Temporal Satellite Data: Effect of Shrimp Cultivation in North Western Province

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ABSTRACT: Habitat encroachment, socio-economic exploitation are well-known factors contributing to the decline of mangroves in Sri Lanka and it is important to identify the area and rate of destruction of the mangrove forests. This study focused to observe the changes of mangrove land cover in surrounding area of Chilaw lagoon in North Western province in Sri Lanka using multi temporal satellite imageries, Landsat MSS, Landsat TM, Landsat ETM and Landsat OLI in 1975, 1987, 2000 and 2014 respectively.
Land use and land cover of the area were derived by unsupervised classification technique and validated by visual interpretation through high resolution Google Earth imageries. Tasseled Cap Transformation (TCT) was applied to images to enhance the distinguishing characteristics of wet surfaces and mangrove vegetation in assigning the land use categories for improved accuracy in image classification. Overall accuracies of classified images of Landsat TM (1987), Landsat ETM (2000) and Landsat OLI (2014) were 78 %, 80 % and 90 % respectively.
The results showed a drastic change of 11% depletion of mangrove extent throughout the study area during the period of 1987-2000 where there was no significant change observed during the period of 2000-2014. The estimated deforestation rate of mangrove cover of -0.43 % was high and the average annual loss was 1.55 ha over a 27 year period (1987-2014). Intensive shrimp farming and urbanization were identified as the main causes for depletion of mangroves. Shrimp farms in 2014 were 455 ha which mainly emerged in mangrove sites. A low ratio of 1:1.33 of existing mangroves to shrimp farms indicates an adverse impact of shrimp farming on mangroves which subsequently affects the environmental sustainability within the study area. Finally, this study proved the potential use of satellite imageries to area quantification of mangrove vegetation in Sri Lankan context.

1. INTRODUCTION

1.1 Background

Mangroves and associated ecosystems are among the biologically most productive, socio-economically important, aesthetically attractive and ecologically indispensable ecosystems in the tropics (IUCN, 2003), characteristics that should place mangroves high on the conservation agenda. Although the rate of decrease of global mangrove cover has slowed since the 1980s, the world and Asian average annual loss rates of mangroves of −0.66 % and -1.01 % during the years 2000–2005 is still alarming (FAO, 2007). Habitat destruction through human encroachment has been the primary cause of mangrove loss. In environmental science point of view, both mangroves and aquaculture are highly interrelated since the shrimp cultivation has a severe effect on mangrove cover. But the literature related to the interdependency of both areas is very few in Sri Lankan context. The mangrove areas of Sri Lanka have also been reduced and impoverished in quality under an increasing human pressure (De Silva and Balasubramaniam, 1985). In recent years, shrimp farming has emerged as a major threat to mangrove ecosystems in Sri Lanka.
In addition to an understanding of the nature and dynamics of local mangrove ecosystems is required, accurate information for managers and policy makers is crucial for rational management of mangroves. The use of Remote Sensing technology on mangroves in combination with Geographical Information Systems (GIS) offers a useful tool for monitoring the coastal environment (Blasco *et al.*, 1998). For Sri Lanka, the use of Remote Sensing has been found to be appropriate for monitoring mangrove vegetation (Guebas *et al.*, 2000), and complemented with other information in a GIS may act as a tool for enforcing conservation.
The major objectives of this study were 1) to quantify the existing mangrove cover in the study area using remote sensing and GIS and 2) to evaluate the spatio-temporal change of mangrove cover due to land use changes including shrimp cultivation within the study area over the last four decades using multi-temporal satellite images.
The study area is located along the western coast, which covers the Chilaw lake, in the North Western province of Sri Lanka (7°27' N, 79°47' E and 7°34' N, 79°50' E) covering a 18 Grama Niladhari Divisions (GNDs) in Chilaw, Madamape and Mahawewa District Secretariat Divisions. East boundary is demarcated by Puttalam – Peliyagoda

road (A3) (Figure 1). The total extent of the study site is 3200 ha. The mangroves of this area belong to fringe or riverine type while recording 16 mangrove species, and observed as most species diverse mangrove along the South Western coast of Sri Lanka (Jayatissa *et al*., 2002).

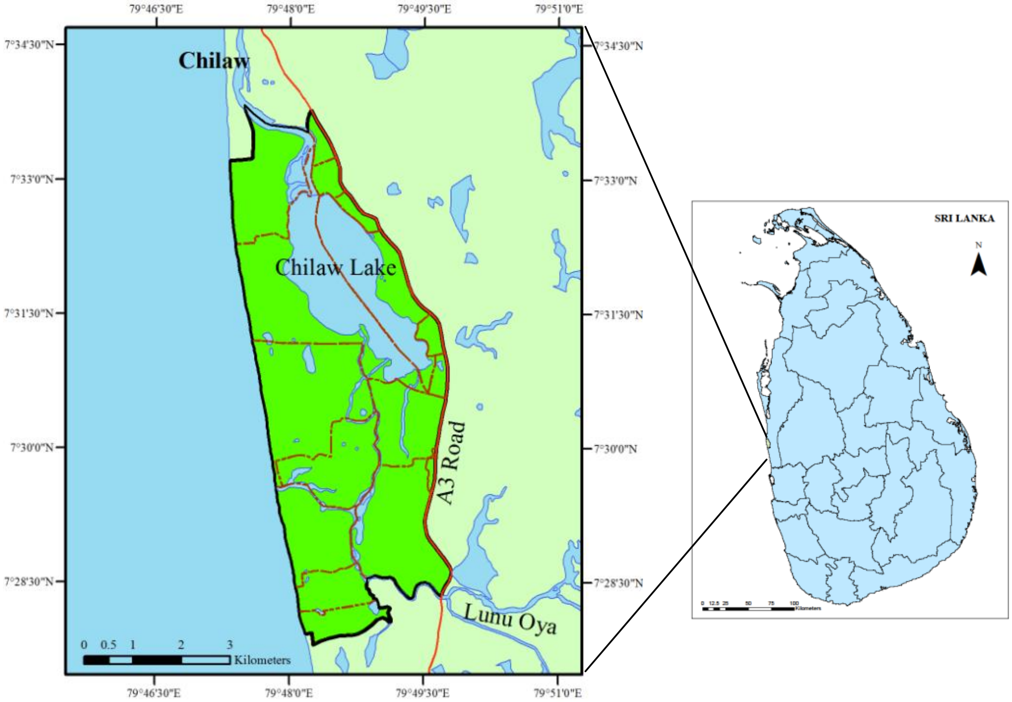

Figure 1: Study Area

2. MATERIALS AND METHODS

2.1 Data and Instruments

The analysis is based on multi-temporal satellite imagery of last three decades in 1975, 1987, 2000 and 2014. The relevant Landsat Satellite images of the study area were downloaded from USGS (Unites States Geological Survey) and GLCF (Global Land Cover Facility) websites which are freely available. High-resolution Google earth images, topographic maps at a 1:50,000 scales (digital) and 1-inch scale map (1:63,360) were used for identification of signatures and accuracy assessment. Image processing and data analysis were performed using EARDAS IMAGINE 9.1 while Spatial Analysis was performed by Arc GIS 9.3.

2.2 Image Classification

The required bands were stacked to form four multi-band images using ERDAS IMAGINE. Since the available images have already been radiometrically corrected and geometrically corrected such corrections were not necessary to perform for this study. ISODATA algorithm unsupervised classification was used for the four satellite images. The methodology adapted during this study is depicted in Figure 2. The stacked scenes subsequently were subsetted to obtain study area.

For the unsupervised classification of 1975 image, the 1-inch scale topographic map was used to identify signatures. 1987 image, 1:50,000 topographic map was used to identify signatures. In a similar way, the Google earth images of 2002 and 2014 were used to identify ground signatures for the unsupervised classification of 2000 and 2014 Landsat image. Furthermore, to identify each signature at the stage of unsupervised classification, the visual interpretation was used for different band combinations. Of a normal satellite image Mangrove forests are best highlighted in NIR, SWIR, and Red (4, 5, 3 band combination). Under this false color composite, mangrove forest turns a unique striking deep orange separating them from all other vegetation in the area. Further, TCT images were used with 1, 2, 3 (RGB) band combination along with the false colour composite of images to distinguish Mangrove vegetation by its luminous blue color while bright orange colour indicates bare lands and blue colour indicates water and moisture (Figure 3). In order to perform the TCT on Landsat OLI image, raw digital numbers were converted to at-satellite reflectance and an algorithm was run using the modeler since no built-in function is available within ERDAS IMAGINE for a direct TCT. Having converted the bands 2-7 to reflectance, the layers were stacked to obtain an image. For Landsat ETM+, TM and MSS images, the inbuilt function in ERDAS IMAGINE was used for TCT. However, for the ETM + image DN to reflectance was performed using metadata and the earth-sun distance related to image acquisition date given by Chander *et al.*, (2009).

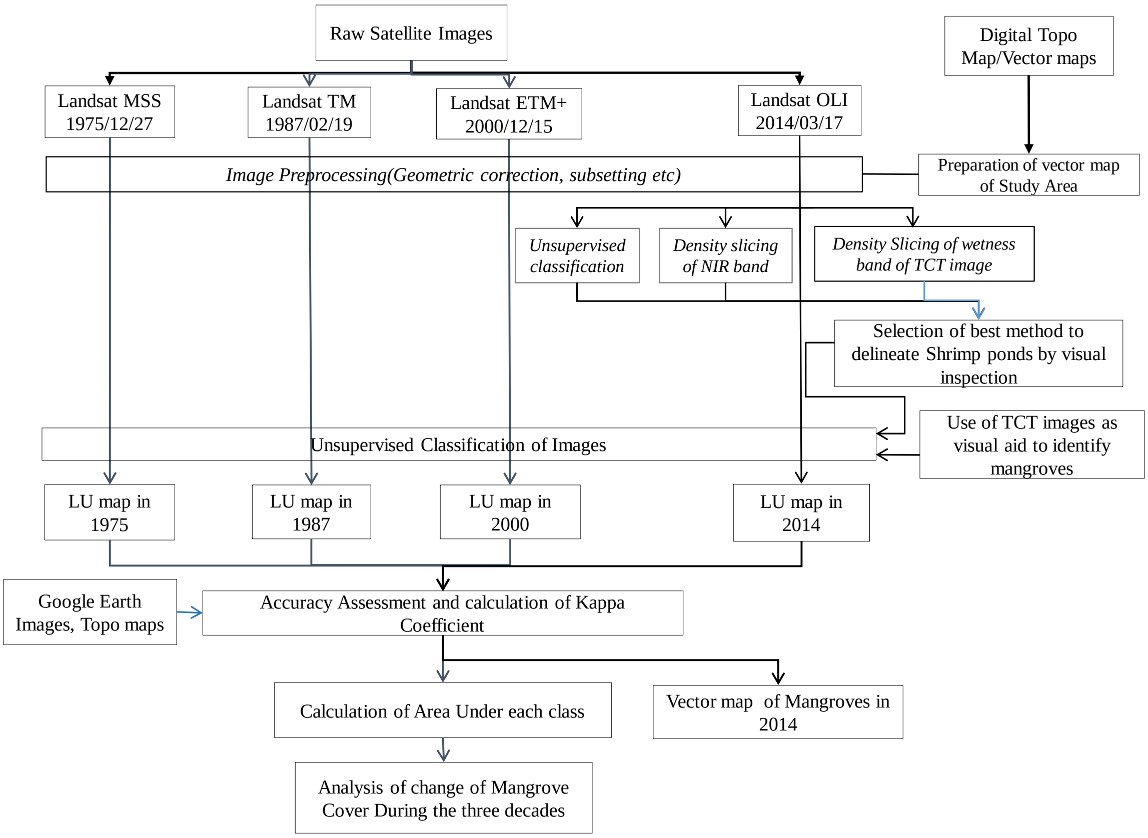

Figure 2: Flow chart of the methodology adapted for the study

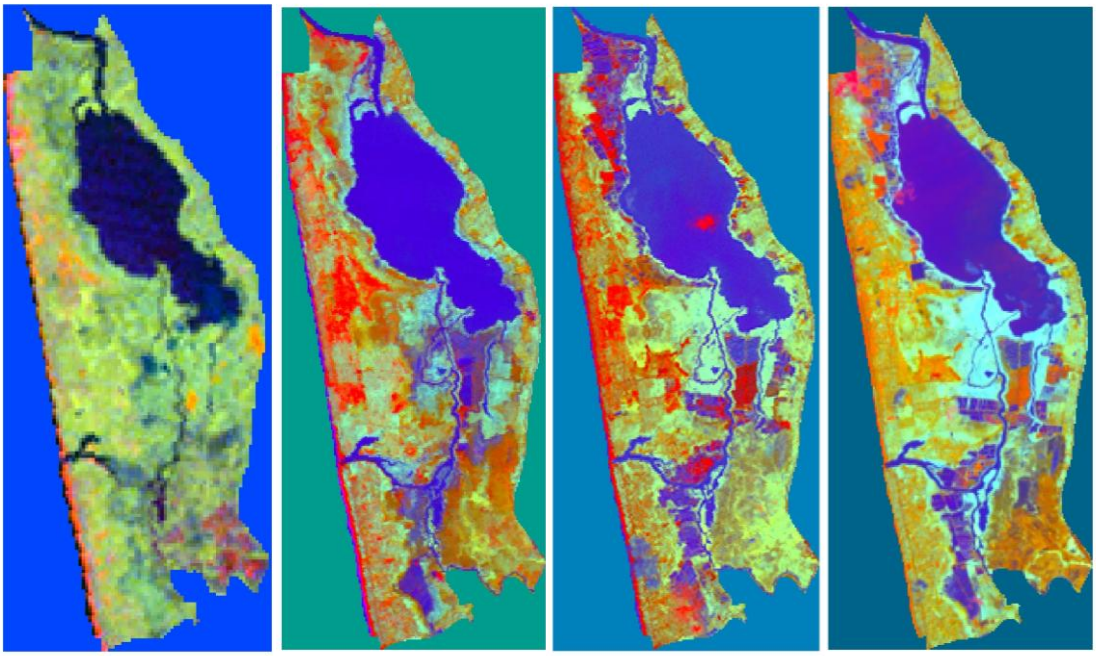

Figure 3: TCT images of each year in 1, 2, 3 band combination (images of year 1975, 1987, 2000 and 2014 from left to right)

25 classes were re-coded down to six broad categories of land uses for each time period as water bodies including Shrimp Farms, Mangroves, Marshes, Coconut and other Vegetation, Paddy and Residential, Barren Lands and Fallow Paddy.

The shrimp farms and water bodies were categorized into a single class as it was difficult to differentiate between the two using the data provided. Onscreen digitization was found appropriate to delineate aquaculture farms to eliminate the classification errors by the unsupervised classification. In order to assure the consistency of

interpretations, the ponds were digitized in a time sequence by adding each of the new ponds appeared over time from 1975 to 2014. The vector files were then overlaid on top of the classified image.
The results were assessed for accuracy in the form of an error matrix. The Kappa coefficient of each image was calculated according to the formula given by Congalton and Green (1999): A total of 50 stratified random points was compared with ancillary data.

3 RESULTS AND DISCUSSION

3.1 Accuracy Assessment of Classification

The overall accuracies for 1975,1987, 2000, and 2014 were 60 % ,78 %, 80 %, and 90 % respectively with Kappa statistics ranging from 0.503 to 0.876 and user's and producers' accuracies of each information class ranged from 42 % to 100 % in most cases. The producer's accuracy in terms of mangrove class ranged from 50 %- 100 % while the user's accuracy of same ranged from 42 % -100 %. In spite of the low accuracy of the mangrove class in Landsat MSS image, the accuracy of mangrove classification of the year 1987, 2000 and 2014 were remarkably high (86 % - 100 %). Classification accuracies of the marsh land use class were comparatively low due to the mixed pixels with paddy.
The results indicated below average accuracy of mangroves in terms of both producer's and user's accuracy (50 % and 42 %) as well as overall accuracy (60 %) for Landsat MSS image. This could be because the resolution of the image is too course for the study especially due to heterogenic nature land cover and small patch like mangrove cover in Sri Lanka. Furthermore, the numbers of bands were fewer than the other Landsat images. The output of the 1975 classified image was less reliable and therefore considering the significant errors that could cause by incorporating the result, the map has only been used as a base map where none of the shrimp farms appear within the study area.

3.2 Results of Unsupervised Classification

Figure 4 depicts the visual comparison of the classified images. Encircled areas indicate major conversions of Land use (Black – Mangrove to Shrimp Farms, White –Mangrove generation, Light Green- Marsh to Shrimp farms and Paddy to marsh, Yellow- Coconut to Residential areas).
In general, the 2000-2014 time period has less distinctive land use changes. In contrary, the 1975-1987 and 1987-2000 time periods indicate drastic changes of land use. Visual comparison of classified images indicates that there had been the definite conversion of mangrove cover to shrimp ponds (the encircled areas in black). Two shrimp farm sites emerged in 1987 has been such conversion (Figure 4). During 1987 -2000 in addition to the considerably large areas of mangroves been converted to shrimp ponds, west and east banks of the lake, almost all the small patches of mangroves had been replaced by small-scale shrimp ponds. However, between same time period, some generation of mangroves could be observed (the encircled areas in white) therefore the figure of original mangrove loss during this period should be actually higher. Urbanization seems to have very little impact on mangroves by visual observation. However growing residential areas have affected considerably on coconut cover (the encircled areas in light yellow) throughout the study years.
Marshes and some coconut cover have also been converted to shrimp ponds as well (the encircled areas in light green). South Western corner of the study area comprises of a paddy field of which a large extent of the northern area has been converted to marsh lands from 1987 to 2000.

3.3 Map of Spatial Distribution of Mangrove Cover of Study Area in 2014

The mangrove cover of 2014 was extracted and a layout (Figure 5) was created to be used in future references of the research.

3.4 Analysis of Temporal Change Patterns of Land Use/Land Cover

After the image analysis, classifying and the processing, types of land uses in the last 40 years were identified. The static land use land cover distributions for each study year as derived from the maps are presented (1987-2014) in Table 1. For each year, Coconut and other vegetation covers prevailed over the other classes, displaying a negative trend. Paddy and marshes were the less significant classes, occupying less than 350 ha except in the year 2000 for marshes and 1987 for paddy. However, it could be noted that paddy in 1987 has been abandoned had converted to marsh lands. According to the mangrove estimates obtained in the classifications, it can be seen that the extent of mangrove forest has been changed from 1975-1987, 1987-2000 and 2000-2014. Calculated Mangrove area is 383.2 ha, 341.6 ha and 341.4 ha in 1987, 2000 and 2014 respectively. The study area experienced a positive trend of the shrimp farming since the emerging of farms in 1987 image. By the year 2014 around 455 ha of ponds were estimated from the digitized polygons. The changes of land use in each time period is depicted in tables 2 and 3.

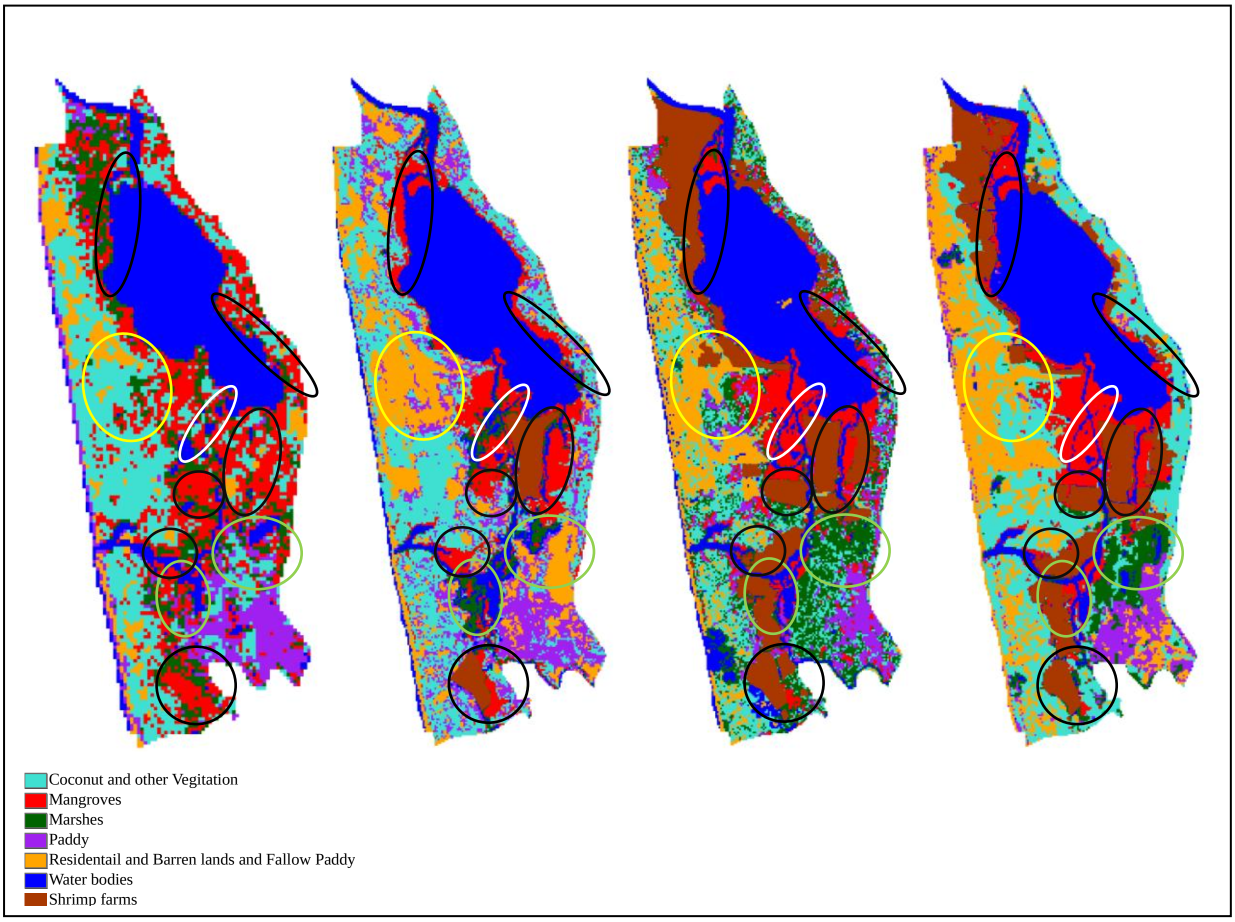

Figure 4: Comparison of classified images in the year 1975, 1987, 2000 and 2014 from left to right

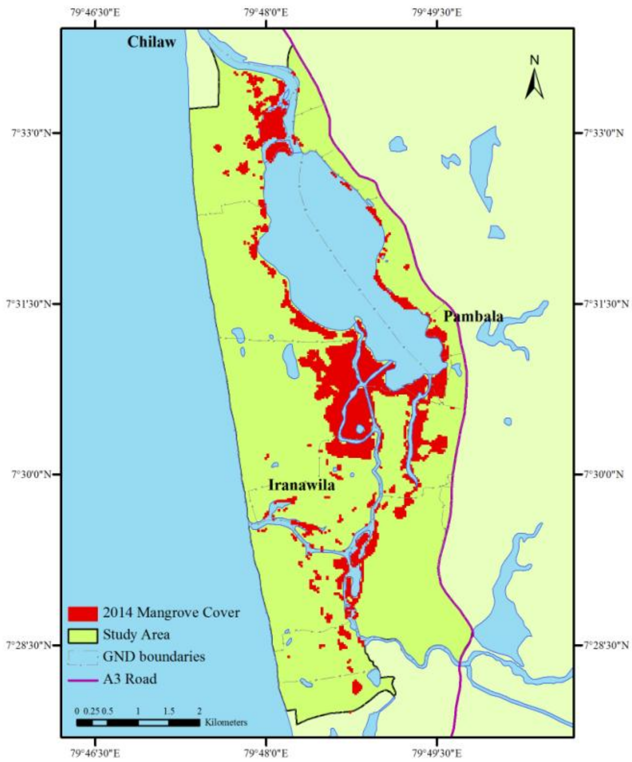

Figure 5**:** The map of spatial distribution of mangrove cover obtained from classification of the Landsat OLI image 2014

Table 1: Land use land cover distribution (1987, 2000 and 2014)

Land use class	1987		2000		2014	
	Area (ha)	% of total area	Area (ha)	% of total area	Area (ha)	% of total area
Water Bodies	714.8	22	659.7	21	518.0	16
Shrimp Farms	98.6	3	522.5	16	455.0	14
Mangroves	383.2	12	341.6	11	341.4	11
Marshes	146.4	5	488.2	15	273.0	9
Coconut and Other Vegetation	857.7	27	539.2	17	764.8	24
Paddy	459.8	14	229.7	7	222.0	7
Residential, Barren lands and Fallow Paddy	544.9	17	426.6	13	628.2	20

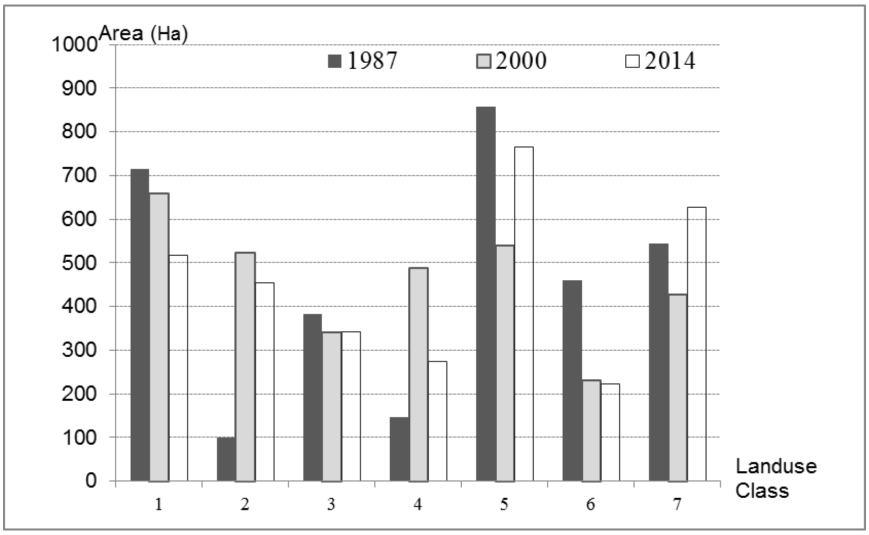

Figure 6 : Nature of relative land cover changes during 1987 to 2014 period
(1- Water bodies, 2- Shrimp Farms, 3- Mangroves, 4-Marshes, 5- Coconut and Other Vegetations, 6- Paddy and 7- Residential, Barren lands and Fallow paddy)

Table 2: Change of land use in each study period 2000-1987 and 2014-2000

	2000-1987		2014-2000	
Land use class	Area (ha)	Change as %	Area (ha)	Change as %
Water Bodies	-55.1	-8	-141.7	-21
Shrimp Farms	423.9	430	-67.5	-13
Mangroves	**-41.6**	**-11**	**-0.3**	**0**
Marshes	341.8	233	-215.3	-44
Coconut and Other Vegetation	-318.5	-37	225.6	42
Paddy	-230.1	-50	-7.7	-3
Residential, Barren lands and Fallow Paddy	-118.3	-22	201.6	47
Average annual loss of mangroves (ha/Yr)	3.2		0.02	
Deforestation rate of mangroves (%)	0.88		0	

Table 3: Change of land use in 2014-1987 (27 years period)

Land use class	2014-1987 (27 years) Area (ha)	Change as %	% of total Area
Water Bodies	-196.9	-28	-6
Shrimp Farms	356.4	361	11
Mangroves	**-41.9**	**-11**	**-1**
Marshes	126.5	86	4
Coconut and Other Vegetation	-92.8	-11	-3
Paddy	-237.8	-52	-7
Residential, Barren lands and Fallow Paddy	83.3	15	3
Average annual loss of mangroves (ha/Yr)		1.55	
Deforestation rate of mangroves (%)		0.43	

3.4.1 Analysis of Change Patterns of Mangroves

From 1987 to 2000 the change of mangrove cover was greater than that for the latter period (2000-2014), at both landscape and class levels. Deforestation rate of mangroves (dn) was calculated with the formula proposed by Palacio-Prieto *et al*., (2004). It showed a drastic change of 11% depletion throughout the study area during the period 1987-2000 (Table 2) but did not change to a great extent, showing a percentage change of 0 % for the 2000-2014 period. The average annual loss of mangrove extent is 3.2 ha and 0.02 ha in 1987-2000 and 2000-2014 respectively while the deforestation rates of mangroves are 0.88 % and 0 %. This cover remained almost constant during 2000 - 2014 periods. It is the least changed class during the particular period.

During the 27 year period, mangroves diminished by around 41.9 ha which is 1 % from the total study area, indicating an average loss of 1.55 ha on a yearly basis (Table 1). It is a negative change of 11 % of the 1987 cover and a deforestation rate of mangroves of 0.43 %.

Expansion of shrimp ponds and urbanization and can be identified as an influence towards major changes occurring to mangrove forest in the study area by visual observation and since those particular land covers are classes which indicate a positive trend. In contrary shrimp farm area has slightly declined during the period of 2000 - 2014.

Table 4 provides information about the ratio of mangrove forest to other types of land use/cover. During 1987-2000 mangrove forests were mainly converted into shrimp ponds. The ratio of mangrove: shrimp farms and mangrove: residential areas have increased.

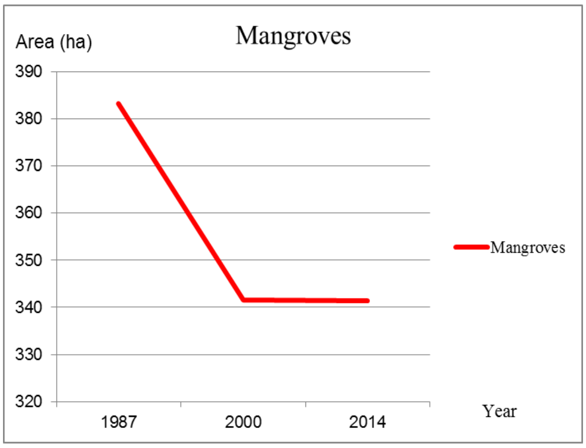

Figure 7: Trend of mangrove cover changes from 1987 to 2014

Table 4: Ratio of mangrove forest cover: land use class

Year	Water	Shrimp farms	Marshes	Coconut Cultivation	Paddy	Residential, Barren lands
1987	1.87	0.26	0.38	2.24	1.20	1.42
2000	1.93	1.53	1.43	1.58	0.67	1.25
2014	1.52	1.33	0.80	2.24	0.65	1.84

3.4.3 Impact of Shrimp Farming On Mangroves

The results reveal considerable loss of mangrove forest as a result of deforestation and shrimp pond in the study area from 1975 to 1987. In 1975 there had been no shrimp farms in the area. However, by 1987 two major shrimp pond sites are visible covering 98.6 ha. Between 1987 and 2000 study area had undergone a staggering increase in the extent of shrimp pond development (430 %). It became evident that mangroves are the main subsidiaries for this activity, whereas shrimp ponds represented mangroves surfaces in 2000 map as well. Most of the farms detected are located near marshes or mangroves. Using digitization of aerial photographs Guebas *et al*., (2002) revealed that shrimp farms had expanded in the Pambala area, mainly at the expense of mangrove forest and coconut plantations. This fact seems to be confirmed by the finding of this study.

By 2014 the shrimp farm area has decreased to 455 ha. The decrease in shrimp ponds between 2000 and 2014 is 13%. It is possible that the satellite imagery was acquired during a period when the ponds were dry. The dry ponds would likely have resembled a barren surface providing similar spectral signatures for both habitat types.

Considering the mangrove cover, the real effects on the structure of this vegetal cover could be worse, since shrimp farming and the associated infrastructure (channels, roads, etc.) pose a risk to the preservation of coastal wetlands and damage the quality of the mangrove cover. It is, therefore, necessary to implement regional studies at higher resolution levels to assess the real impact on this coverage, as well as on wetlands. In general, it is possible to conclude that the area of wetlands in the study declined from 1975 to 2014 due to the expansion of shrimp farming.

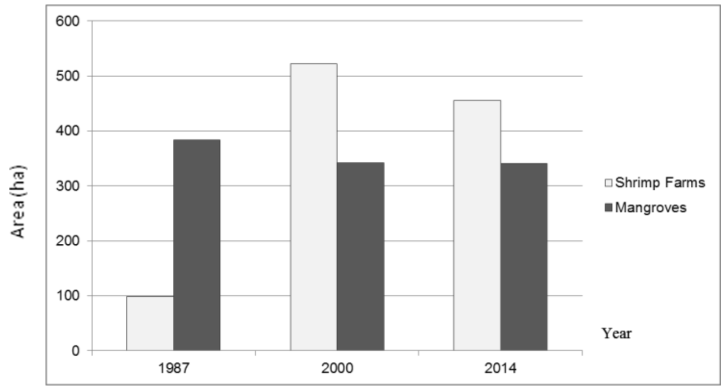

Figure 8: Variation of mangrove cover in contrast with shrimp ponds (Area in ha)

4. CONCLUSIONS

This study proved that remote sensing offers a realistic way of continuously monitoring the mangroves and the usefulness of remote sensing coupled to GIS.

It is concluded that mangrove forests are decreasing within the study area. Intensive shrimp farming and urbanization were identified as the major reasons for changes of mangrove forest areas and led to the degradation of mangrove forest, the loss of mangrove forest and ecological disturbance. Despite the slight generation of mangroves observed, a deforestation rate of mangrove cover of -0.43 % over a 27 year period was calculated for 1987-2014 is lesser than the world average annual loss (-0.66 %) which indicates that mangrove deforestation of Sri Lankan context is less critical compared to the global trend. However intensive shrimp farming has already put the mangroves under pressure and poses immediate sustainability questions. Similar to literature regarding shrimp aquaculture's impacts in other regions of the world, mangroves are suffering great losses due to displacement by shrimp ponds.

To revert this negative tendency and to guarantee a long-term continuity of stable conditions in this region, it is necessary to implement integral management strategies. These strategies should be based on reliable inventories and monitoring programs of mangroves. The results obtained in this study are of use to determine the general trends of change in the landscape elements from 1975 to 2014. The very high accuracy of the Landsat OLI image classification indicates that in future similar studies can be carried out at a higher level of accuracies especially to quantify the small patch-like distribution of mangroves exist in Sri Lankan context ensuring the requirement of island-wide mangrove inventories.

At the same time, more mangrove afforestation should be done, thus evolving towards integrated abandoned shrimp farms could be both rehabilitated, and serve mangrove regeneration purposes.

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