Change detection of mangrove coverage in Puttalam Lagoon of Sri Lanka using satellite remote sensing techniques

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Abstract

Mangroves as a unique ecosystem provide wide range of benefits and services to the environment and people. Interconnectivity among the key habitats of mangroves, seagrass and coral reefs is vital for diversity of coastal ecosystems. Extensive mangrove coverage in and around Puttalam Lagoon and associated waters, located in Northwestern coast of Sri Lanka is significant to the fish production. However, expansion of shrimp aquaculture in 1980's caused a decline of vast extent of mangrove coverage. Spatial and temporal changes of mangrove coverage during a 38 year period expanding from 1977 to 2015 were investigated. Landsat data acquired in the different years; 1977, 1988, 2000, 2005, 2010 and 2015 were analyzed and processed through the four steps; image pre-processing, image classification, change detection and projection of changes. The analysis of the mangrove extent in the area shows that the mangrove coverage had been declined by 62% within the 38 year period. Aquaculture expansion, particularly shrimp culture was the major cause for the decline of mangrove. Totally, 1371 ha of mangroves had been deforested to establish shrimp ponds during the period of 1988-2000. However, during the period from 1996 – 2000, in total 417 ha of shrimp ponds were abandoned, due to a virulent spread of white spot and yellow head viral diseases. The other important factor, contributed to the decline of mangroves is the expansion of salt industry by 280% during the period of 2000-2015. Totally, 65% of the abandoned shrimp ponds were converted into saltpans in this period. The projected result of mangrove changes by MARKOVE analysis shows that mangrove coverage is to decline by approximately 314 ha (7%) by 2020, if the current trend continues. The rapid increase of the population in the Northwestern coastal area is another factor that contributes to the decline of mangrove stands in recent times. Therefore, more effective land use planning is critical at this milieu to conserve mangrove ecosystems, while expanding the local industries in a sustainable manner.

Keywords: Mangrove, Change detection, Change projection, Remote sensing

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Introduction

Mangroves are a very unique ecosystem, which inhabit an area at the sea-land interface. It serve as a natural breakwater for tidal currents and protection of the shoreline from storms surges and tsunami, thus protect the land area from coastal erosion and stabilize the shoreline. Mangrove ecosystems also serve as habitats for coastal fish and wildlife. However, it is among the most threatened habitats around the world. Decline of mangrove forest coverage is rampant across the globe presently (Giri, *et al.*, 2011).

Sri Lanka is left with only about 0.1-0.2% of its land area under mangrove coverage (Karunathilake, 2010). Mangroves are mainly found scattered in and around the lagoons and river estuaries, along the Northern, Northeastern and Eastern coast. The largest extent of mangrove is found in and around Puttalam Lagoon, Dutch Bay and Portugal Bay in the Northwestern coast (De Silva and De Silva, 1998). Establishment and rapid expansion of aquaculture industry particularly, shrimp culture in 1980's along the lagoons and estuaries with the government patronage resulted destruction of vast extent of mangrove coverage in the area (Amarasinghe and Balasubramaniam, 1992). However, the aquaculture industry faced a sudden collapse due to a virulent spread of white spot and yellow head viral diseases from 1996 onwards (Munasinghe *et al.*, 2010). Some of the abandoned shrimp ponds are converted into saltpans. Besides, destruction of mangrove is continued to take place in the area due to other anthropogenic influences such as land reclamation, construction, tourism, agriculture, coastal developments and wood extraction. Therefore information on changing mangrove extent is essential for resources management in a sustainable manner. This study was conducted to identify the changes on mangrove cover in the Puttalam Lagoon and associated waters, during past 38 years based on the Landsat satellite images acquired during the period of 1977 to 2015.

Study area

Puttalam Lagoon is located in the Northwestern Province, Sri Lanka, which is one of the largest inland brackish wetlands in Sri Lanka with an area of 36,426 ha (IUCN, 2008). The lagoon is located in dry and arid zone and receives annual average rainfall of 1,150 mm with an average annual temperature 28°C (Amarasinghe and Balasubramaniam, 1992). The natural environment of the area is dominated by estuarine vegetation including patchy mangrove, fringing salt marshes, mangrove associates and seagrass. The map of the study area is given in Fig. 1.

Materials and Methods

Multispectral Landsat image with Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+), Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), acquired from the United States Geological Survey (USGS), at different years during the period from 1977 to 2015 were used as the base data for the study. Table 1 lists the Landsat products, used in this study and their characteristics. The Images are of GEOTIFF format obtained through the Worldwide Reference System (WRS) Path 142 and Row 054 and projected to UTM Specific Parameters of Hemisphere "N", Zone "44".

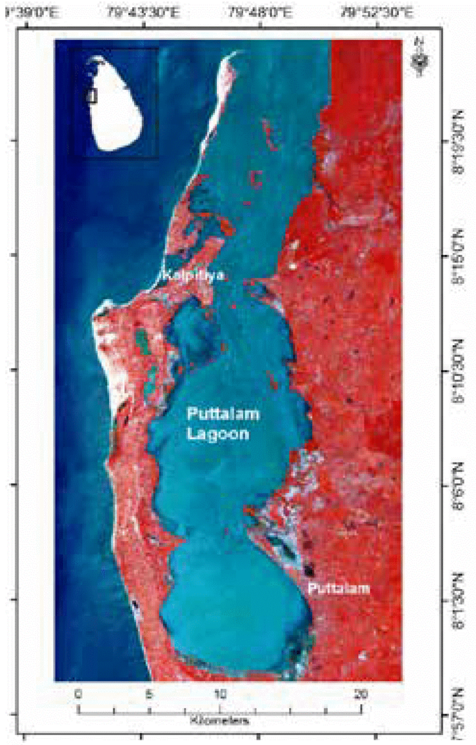


Fig. 1. Map of the study area

Table 1. Specification of Landsat image.

No	Sensor	Spacecraft	Acquisition date	Resolution (m)
1	MSS	LANDSAT_2	1977-01-26	60
2	TM	LANDSAT_5	1988-02-06	30
3	ETM+	LANDSAT_7	2000-12-15	30
4	ETM+	LANDSAT_7	2005-03-16	30
5	TM	LANDSAT_5	2010-02-18	30
6	OLI_TIRS	LANDSAT_8	2015-03-20	30

Data is processed by four steps; image pre-processing, image classification, change detection and projection of changes. The methodology, adopted in processing the Landsat data is given in flowchart (Fig. 2).

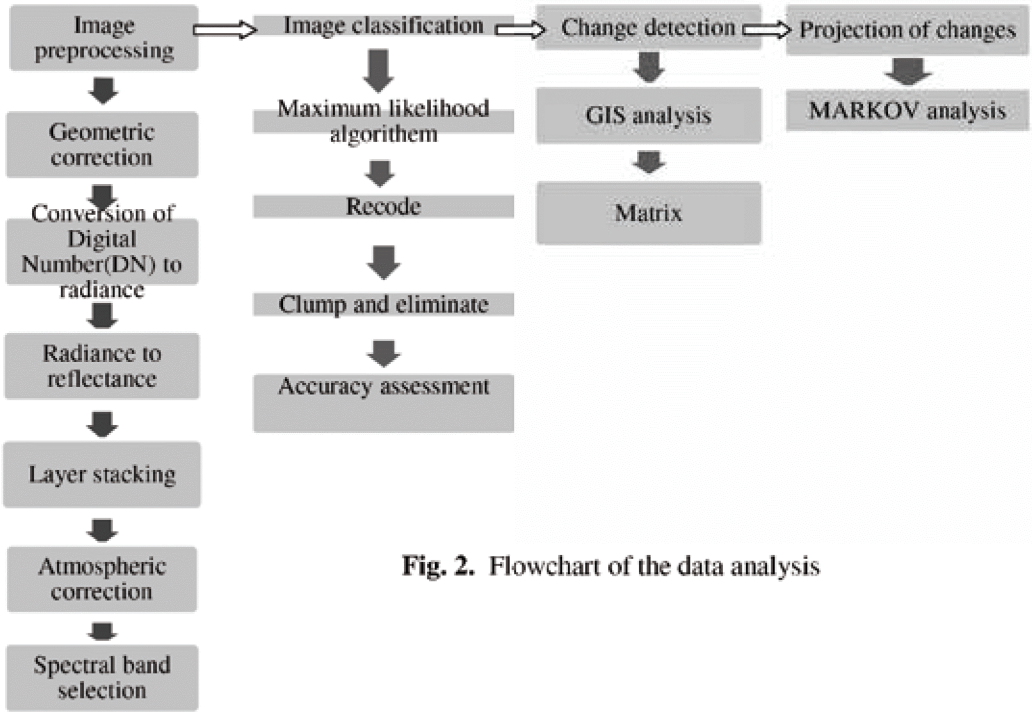


Fig. 2. Flowchart of the data analysis

Image preprocessing: Image preprocessing is required due to the distortion of sensors. The steps involved in image preprocessing are as follows;

Geometric correction: Each image is geometrically corrected to WGS 84, UTM 44 time zone maintaining the RMS error about 0.5.

Conversion of DN to radiance: TM, and ETM+ sensors have different radiometric resolutions (Table 1), hence their respective digital numbers (DNs) carry different levels of information and cannot be directly compared. Therefore, they were converted to absolute units of radiance W m^{-2} sr^{-1} μm^{-1}applying the following formula;

$L_\lambda = \frac{\mathrm{LMAX}_\lambda - \mathrm{LMIN}_\lambda}{[(\mathrm{Q}_{\mathrm{calmax}} - \mathrm{Q}_{\mathrm{calmin}})]} \times (\mathrm{Q}_{\mathrm{cal}} - \mathrm{Q}_{\mathrm{calmin}}) + \mathrm{LMIN}_{\lambda,}$ Where,

L_λ= Spectral radiance at the sensor's aperture (W m^{-2} sr^{-1} μm^{-1})

Q_{cal}=Quantized calibrated pixel value (DN)

Q_{calmin}= Minimum quantized calibrated pixel value corresponding to $LMAX_\lambda$ (DN)

$LMIN_\lambda$= Spectral at-sensor radiance that is scaled to Q_{calmin}(W m^{-2} sr^{-1} μm^{-1})

$LMAX_\lambda$= Spectral at-sensor radiance that is scaled to Q_{calmax}(W m^{-2} sr^{-1} μm^{-1})

Conversion of radiance to reflectance: Normalization of solar irradiance by converting spectral radiance to planetary reflectance can be achieved in this process. The equation applied is as follows;

$$\rho_\lambda = \frac{(\pi . L_\lambda . d^2)}{(ESUN_\lambda . \cos\theta_s)}$$

Where;

ρ_λ= Planetary Top of Atmospheric (TOA) reflectance

π= Mathematical constant equal to 3.14159

L_λ= Spectral radiance at the sensor's aperture (W m^{-2} sr^{-1} μm^{-1})

d^2 = Earth-sun distance (astronomical units)

$ESUN_\lambda$= Mean exoatmospheric solar irradiance (W m^{-2} μm^{-1})

$\cos\theta_s$= Solar zenith angle (degrees)

The equation applied for the Landsat 8 images as follows;

$$\rho_\lambda = \frac{M_\rho . Q_{Cal} + A_\rho}{\sin(\theta)}$$

Where;

ρ_λ= Top-of-Atmosphere Planetary Spectral Reflectance, without correction for solar angle. (unitless)

M_ρ= Reflectance multiplicative scaling factor for the band (REFLECTANCEW_MULT_BAND_n from the metadata).

A_ρ = Reflectance additive scaling factor for the band (REFLECTANCE_ADD_BAND_N from the metadata).

Q_{Cal} = Level 1 pixel value in DN

θ = Solar elevation angle

Layer stacking: Radio metrically corrected bands were combined into a single multispectral image file for better visualisation.

Atmospheric correction: Corrections were made to remove the effects of the atmosphere on the reflectance values of images by employing pre-calculated atmospheric conditions based on the MODTRAN radiative transfer code at ATCOR2 tool. Sun and sensor geometries were modified according to the image recording conditions as extracted from the image's metadata.

Spectral band selection: Band selection is mainly required to improve the interpretability of information in images for viewers. Spectral profile of sampled area shows that the mangrove vegetation has a low reflectance on infrared bands (IR Band 5 and 6), since the habitat being intertwined with mud, sediment and water (Fig. 3). Band combination for image classification is chosen by applying Normalized Mean Distance (NMD) formulae to separate mangrove and other vegetation.

$$\dot{d} = \frac{(\mu_1 - \mu_2)}{(\sigma_1 + \sigma_2)}$$

Where,

μ_1 and μ_2 - mean values (Chen *et al.*, 2010)

σ_1 and σ_2- standard deviation of mangrove and other vegetation.

Spectral Band of 7,5 and 4 were chosen for the classification.

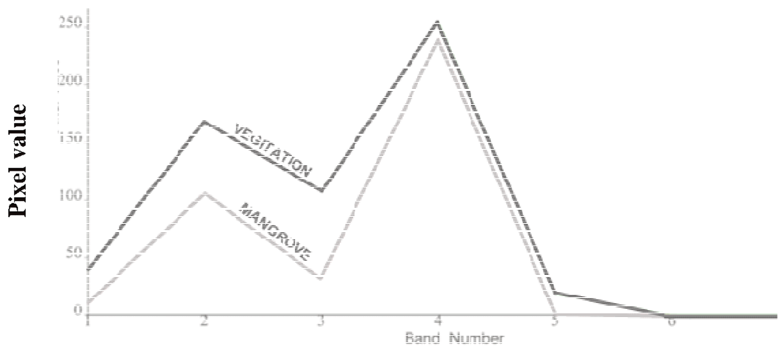


Fig. 3. Spectral profile of vegetation and mangrove

Image classification

Supervised classification: The method is based on spectral signatures of different land cover types. The Image DN values were divided in to seven classes as mangroves, abandoned/active shrimp pond, saltpan, non-mangrove vegetation, water and cultivation.

Clump and eliminate: New value was assigned to contiguous cells within each map category using "Region group" shape analysis function in the clump process. Illuminate function was employed to remove the isolated pixel in the classified image.

***Accuracy assessment*:** The assessment was conducted by an error matrix with the ground-truthed data to the classified image of 2015. Randomly 23 locations, obtained by ground truthing were used as reference data. Overall accuracy, user's accuracy, producer's accuracy and Kappa Statistics were obtained.

Change detection

It is a process to measure how the pixel values of a particular area have changed between two or more time periods. The change detection between periods from 1977 to 2015 was examined by a matrix function. Matrix analysis makes a thematic layer that contains separate classes for every coincidence of classes in two layers. Change analysis was performed in different periods as 1977-1988, 1988-2000, 2000-2005, 2005-2010, 2010-2015, and 1977-2015.

The loss and increase of mangrove coverage were calculated by;

$$\left(\frac{S_j - S_i}{S_i}\right) X\ 100$$

Where, S_j = mangrove coverage

S_i = other land use classes in the i^{th} and j^{th} years respectively

Prediction modelling

Predictions of future changes of the land cover/use were made based on past changes. Qualitative land cover images for 2010 and 2015 were used to detect the future changes, which assumed to be effective for predicting near future mangrove changes. MARKOV's transition probability matrices were used to project the changes. Transition areas matrix evaluates the temporal changes on the number of pixels that are expected to change in two images over a specified time. Spatially, an explicit weighting factor was created at the CA-MARKOV analysis process for each of the suitability.

Software used

Earth Resource Data Analysis System (ERDAS) Imagine 2011 and IDRISI Selva 17.0 software were used to image classification and prediction respectively.

Results

Spatial and temporal distribution of mangroves

Spatial distribution of mangroves at different periods of 1977, 1988, 2000, 2005, 2010 and 2015 is extracted by the analysis and mapped as shown in Fig. 4. Most of the mangrove patches are scattered at the lagoon, river interface of Kala and Me Oya and on islands. Extent of the mangrove, abandoned/active shrimp farms and saltpans of respective year, estimated, based on the total of land area is given in Table 2 and mapped as shown in Fig.4.

Table 2. Extent of mangrove, active/abandoned shrimp farm and saltpan

Year	Mangrove		Shrimp Farm (ha)				Salt pan	
	Area (ha)	%	Abandoned	%	Active	%	Area (ha)	%
1977	4,366	3.8	-	-	0	0	244	0.2
1988	3,450	3.0	-	-	0	0	349	0.3
2000	2,255	2.0	417	0.4	954	0.8	494	0.4
2005	2,005	1.8	776	0.7	492	0.4	596	0.5
2010	1,897	1.7	1231	1.1	106	0.1	663	0.6
2015	1,640	1.4	793	0.7	72	0.1	1,427	1.2

The validation (accuracy assessment) results of the classified image of 2015 with ground reference data are given in Table 3. The overall accuracy of the analysis is attained 86.9%.

Table 3. Accuracy assessment result by a confusion matrix for the classified image 2015

Class Name	Reference Total	Classified Total	Number Correct	Accuracy (%) Users	Producers
Mangroves	9	8	8	89	100
Abandoned shrimp pond	2	2	1	50	50
Saltpans	6	6	5	83	83
Total	23	23	20		
Overall classification accuracy = 86.9%					
Overall *Kappa* statistics = 0.816					
Conditional *Kappa* statistics for each category					
Class name	*Kappa*	Abandoned shrimp ponds		0.452	
Mangroves	1.000	Saltpans		0.775	

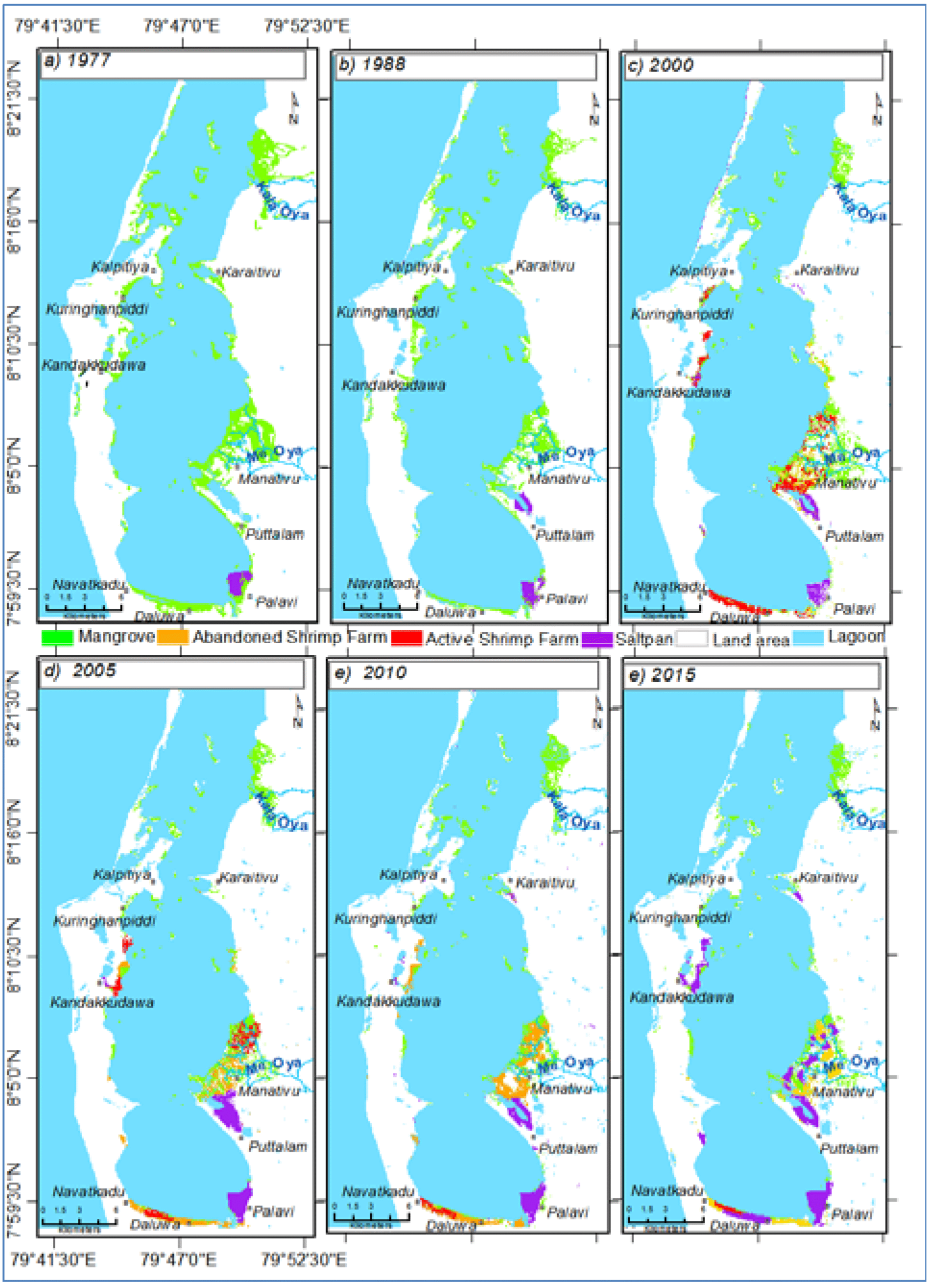


Fig. 4. Spatial distribution of mangroves, active/abandoned shrimp farms and saltpans during the period of 1977-2015

Change detection of mangrove coverage

Totally, 1371 ha was deforested to construct shrimp culture ponds from 1988 to 2000 (Table 4). The annual average rate of land use changes of mangroves, shrimp farms and salt pans is calculated and mapped as shown in Fig. 5. According to the table 4, the highest mangrove loss is recorded during the period of 1988-2000, amounting to about 27%. The total loss and recovery of mangrove coverage during 38 years period is approximately 62 and 9% respectively. The largest conversion of mangrove into shrimp ponds is recorded during the period of 1988-2000, amounting to 421 ha. Conversion of 653 ha of abandoned shrimp pond into saltpans is recorded during the period of 2010-2015. The mangrove loss could be seen in Manalthive and Palavi areas while mangrove recovery mainly recorded along the Kala Oya, Mee Oya rivers and islands (Fig. 5).

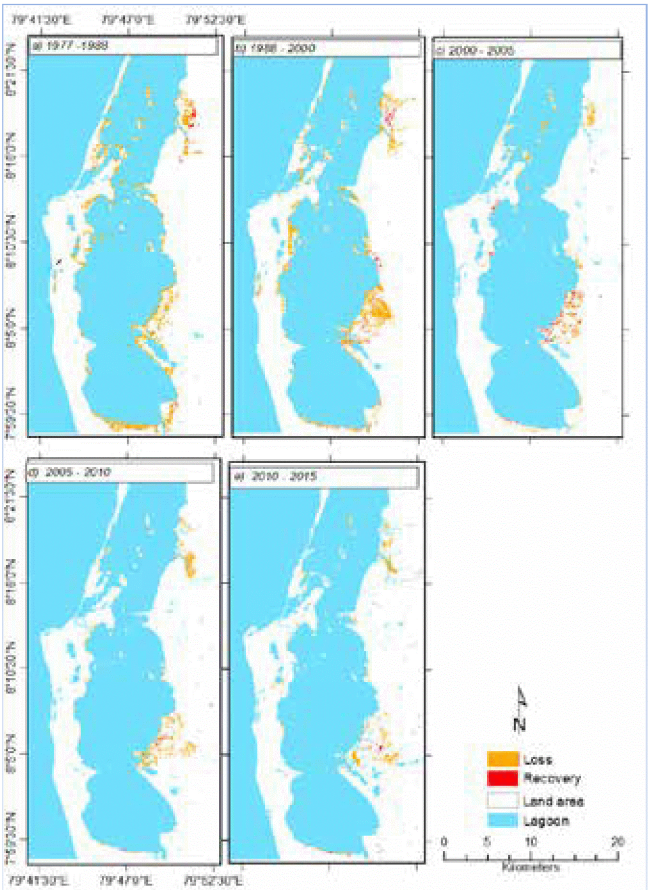


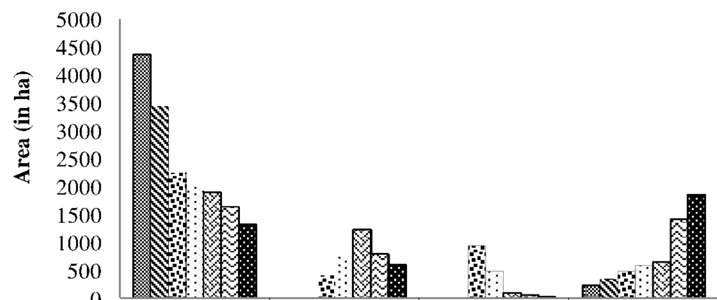
Fig. 5. Change of mangrove coverage (loss and recovery) during the period of 1977-2015

Table 4. Land use changes of mangroves, shrimp farms and salt pans

Period	Mangrove		Mangrove to		Shrimp Farm to Abandoned shrimp farm	Abandoned shrimp farm to Salt Pan
			Shrimp farm	Saltpan		
	Loss (%)	Recovery (%)	(Extent in ha)			
1977-1988	21	4	0	113	0	0
1988-2000	27	1	421	80	0	0
2000-2005	6	1	73	23	171	67
2005-2010	2	1	55	231	258	152
2010-2015	6	2	29	102	224	653

Prediction of changes on mangrove coverage

Primary objective of prediction of the future changes of mangrove coverage is to understand the impact of aquaculture and salt industry on existing mangrove coverage. Projected result of mangrove changes shows that mangrove coverage is further to be declined by 314 ha, by 2020, which is about 7% of the existing mangrove coverage (Fig. 6).The area of saltpans would expand by 13% in 2020.



	Mangrove	Abandoned shrimp pond	Active shrimp pond	Salt pan
1977	4366	0	0	244
1988	3450	0	0	349
2000	2255	417	954	494
2005	2005	776	492	596
2010	1897	1231	106	663
2015	1640	793	72	1427
2020 (Projected)	1326	604	30	1854

Fig. 6. Comparisons of classified results of mangroves, active/abandoned shrimp ponds and salt pan changes with projected result for 2020

Discussion

The findings of this study are indicated that land use changes had exerted significant impact on the mangrove coverage, during the period from 1977 to 2015. Aquaculture development, particularly shrimp industry began in 1980's with the government patronage is the major cause for declining the mangrove coverage. Most of the shrimp ponds were constructed on mangrove areas, even though they help to increase the productivity of shrimp farms. Approximately 1300 ha dedicated to shrimp culture by the year of 2000, though not all of this area is in operation. Due to a viral disease in 1996, the shrimp industry began to collapse. As a result the area of abandoned shrimp pond increased from 0 ha in 1988 to 1231 ha in 2010. During the period of 2010-2015, almost 65% of the abandoned shrimp ponds were converted into saltpans. Less possibility of the abandoned shrimp pond for agricultural uses due to the high salinity levels in the soils could be the reason for converting them into saltpans. Adjoining mangrove areas of these abandoned shrimp ponds were also destructed for the construction of saltpans. The tendency to convert abandoned shrimp ponds into saltpan was widely practiced at Daluwa, Navakkadu, Kuringhanpiddi, Kandakuwa and Manalthive (Fig.4). Mangrove destruction mainly occurred in Manalthive, Palavi, Navakkadu, Karative, Kuringhanpiddi and Kalpitiya areas.

As per the results of projection of land use, deforestation of mangrove is expected to continue due to the expansion of salt industry and population growth. Therefore, more effective land use planning is rather important at this milieu to conserve the mangroves while expanding the local industries in a sustainable manner. Further, the mangroves shall be restored at 604 ha of abandoned shrimp ponds by adopting better management practices to reduce the pressure on the mangrove ecosystem.

Conclusions

The study was intended to investigate spatial and temporal changes of mangrove coverage in and around Puttalam Lagoon, using multi-spectral Landsat satellite images. The accuracy attained is 86.9%, which indicates that the freely available Landsat imageries with 30 m spatial resolution are capable of detecting the long term changes of mangrove extent over a large area. The analysis indicates that the mangrove coverage had declined by 62% within the 38 year period from 1977 to 2015. Aquaculture practices particularly shrimp culture, which commenced during the 80's was a major cause for loss of mangrove area. The shrimp industry had increased by 59% during the period of 1988-2000 and a total extent of 421 ha of mangrove area was converted into shrimp ponds.

The shrimp industry had collapsed in mid 90's, leading to abandoning of 1231 ha of shrimp ponds by 2010. However, there was a propensity to convert these abandoned ponds to saltpans after 2005. The mangrove coverage is expected to further decline by 7% in 2020. Therefore, institutional and policy interventions are needed for better land use management, especially to sustainably manage the mangroves, which are vital for the productivity of the lagoon and associated waters.

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