Assessment and change analyses (1987-2002) for tropical wetland ecosystem using earth observation and socioeconomic data

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Abstract
The two components of the study reflect assessment and change analysis of a tropical wetland in Sri Lanka. The first section explains spatial classification using pixel level-disaggregated image analysis and refined aggregated image analysis and comparison of information extracted by all methods to analyse a better classifier. The second section illustrates change analysis calibrating the land change modeller (LCM) [IDRISI-Andes]. Key observations: a) visual interpretation provides comprehensive blueprint of the wetlandscape compared to supervised and unsupervised classifiers b) change in landscape pattern reflect substantial transition in wetland use. Validation using field coordinates and socioeconomic data showed kappa value (%) of 87.

Keywords: Wetland, tropical, earth observation, change analysis, land change modeller (LCM- IDRISI), socioeconomic.

Introduction
Land use changes in many countries are progressively degrading wetlands with the expansion of agriculture and the development of water resource infrastructure being amongst the major drivers of adverse change globally [Dudgeon et al., 2005; Finlayson et al., 2005]. The actual extent of wetland loss globally is not well known—in some areas more than 50% and sometimes more than 85% of specific wetland types have been lost, but it has not been possible to yet ascertain with any certainty the extent of wetland loss globally [Finlayson et al. 2005]. Management responses to stop and reverse the degradation and loss of wetlands have been proposed, with an increased emphasis on rehabilitation and restoration, but in many instances these responses are not supported by sufficiently integrated information
and data collation and analysis [Finlayson et al., 1999]. It is widely acknowledged that information needs in support of wetland management are multi-scalar—including global, regional and national assessments to guide policy-making [Nagabhatla et al., 2007]. The Ramsar Convention [1971] on Wetlands has long recognised the need to develop techniques that can fill gaps in baseline inventory and has supported the development and application of inventory techniques including the application of multi-scalar remote sensing and GIS [Finlayson et al., 1999; Davidson and Finlayson 2007]. The Convention also emphasizes on prioritization of wetland management guided by local specific information on wetlands including assessment and monitoring. Monitoring wetland change is of paramount importance to understand their ecological structure, hydrological function and environmental flows. Spatial identification of complex coastal system is difficult owing to the highly fluctuating hydrodynamics of the wetlands that result in uncertainty in quantifying the wetland communities. Given these challenges, earth observation resource systems have shown high potential to provide an excellent alternative for such analyses as explained by Fichera et al. [2012].

In response to the increasingly recognised data limitations and the need for further information and analyses Rebelo et al [2010] reported on several initiatives using Earth Observation to provide such information, including an analysis of change in specific wetlands. The latter is extended further in this paper with the specific purpose of testing geospatial approaches at a local scale to measure and understand the dynamics of change in coastal wetlands of Sri Lanka.

The wetland complex is an important component of the coastal ecosystems of western Sri Lanka and is constantly subjected to increasing pressure from land use changes linked with changes in the socio-economic status of the local communities. To address this concern, the geospatial analysis is related with socio-economic data in order to configure the spatial outcome with the wetland dependant livelihoods. The study relates spatial trends with socio-economic profiles of local communities to develop an in-depth understanding of the information and monitoring needs for MMNL [Muthrajawela marsh-Negombo lagoon-MMNL] wetland ecosystem.

The study was of specific interest to the Sri Lankan Central Environmental Authority (CEA) which has in recent years assumed more and more responsibility for wetland management and has supported the production of a national wetland inventory [IUCN Sri Lanka and the Central Environmental Authority, 2006] as a basis for further wetland assessment and monitoring. As a major stakeholder, CEA was involved in the project right from the onset–planning, method identification, field surveys and in consulting the local inhabitants. The project was undertaken with specific consideration of both the technical and social requirements necessary to provide information that could be used to inform decision making.

Two key objectives 1) wetland assessment integrating the biophysical and socio-economic attributes in a geospatial domain and test the suitability of different image classifiers 2) examine methods and models [LCM] for wetland change analyses.

### Site Description

MMNL is located along the west coast of Sri Lanka covering an area of approximately 12 000 hectares (IUCN Sri Lanka and Central Environmental Authority, 2006). Muthurajawela
[located at 7°03’N and 79°55’E] is the largest saline coastal juvenile peat bog in Sri Lanka, which together with the Negombo lagoon [with geographic coordinates: 7°06’-7°12’N and 79°49’-79°53’E] forms an integrated coastal wetland ecosystem. The region falls under four administrative divisions (Divisional Secretariat [DS] levels viz. Ja Ela, Katana, Waattla and Negombo) and covers 85 Grama Niladari [GN] Division (GN is the smallest unit of administration in Sri Lanka) (Fig. 1).

Reports trace the origin of the marsh-lagoon complex to about 5000 years BC (CEA/Euroconsult, 1991). The key water source to the marsh is Dandugan Oya (a small river) with a catchment of 727 sq km. The marsh is also crossed by canals (Dutch and Hamilton) constructed during the colonial period. The rainfall is between 2000-2500 mm [Samarakoon and Renken, 1999] (Fig. 2).

The wetland complex listed as one of 12 priority wetlands in Sri Lanka (in 1996) is an ecologically significant and economically strong zone and a popular recreational destination. The northern part of the complex was declared a wetland sanctuary owing to high endemicity in marine and terrestrial components. As of its proximity to a rapidly developing urban area; over past decades, the wetland has observed degradation resulting from inadequate planning and mounting anthropogenic interventions viz., encroachment and infilling of the marsh, heavy industrialisation, canal sedimentation and pollution that has severely affected the water flow and its biodiversity profile [Nagabhatla et al., 2007]. Given this situation, an integrated assessment was undertaken by the local government authority (CEA) to investigate key ecological-socio-economic drivers of change and address information needs of the wetland.
Figure 2-Rainfall variation in MMNL from 1992-2002 (this data was useful in multiple ways, first to selected the cloud free season for ordering spatial data, to capture seasonality by using temporal data sets and secondly to verify the analysis on flooding pattern and increase in marshy area in different time periods).

Method

Component 1: Spatial Analyses of Muthrajawela marsh-Negombo lagoon

The first component of the study addresses the ambiguity in classifying wetland communities demonstrating automated, semi-automated and visual classifiers to delineate coastal wetlands. The scale of classification was 1:50,000 and the projection used is UTM WGS 84, Zone 44. The spatial information combined with spectral knowledge, and further coupled with ground control points (GCP’s) was integrated to derive the wetland cover for 1987, 1992 and 2002 using the multispectral thematic mapper (MSS-TM) and enhanced thematic mapper (ETM+) Landsat images (Tab. 1 and Fig. 1).

An automated supervised classifier [Maximum Likelihood] in ERDAS along with the integration of the ancillary topographic data [stream network, road and toposheet maps number-59 Negombo-Published by Survey Department of Sri Lanka in First Edition-1990] was used to derive a classified output [land cover/use map]. The non-availability of the cloud free seasonal data (January–March) is a limiting factor in spatial classification, to overcome this, Google Earth images were referred as appropriate. The land cover/use thematic layer functioned as the base map for the change analysis process as we intend to capture the transitions (conversions) between wetland and non-wetland categories. The GCP’s collected (47 pre-classification and 53 collected post-classification) using a DGPS, along with the information gathered from the focal group discussions added for the validation and accuracy assessment via Kappa statistics. Wetland classes were defined based on the local understanding and in conjunction with Ramsar and LCCS (Landuse Classification System by FAO) [Gregorio, 2005] nomenclature. This provided a case to comment on the
applicability of global wetland nomenclature for local-level classification. The second section of this component discusses the image processing technique as a precursor to spatial classification. The Landsat TM images were subjected to signature separability/ discriminability analysis to determine how distinct the signature of one land covers class is from the other. The analysis also exhibits how a particular land-cover unit responds to the band length [particularly in context of separation between wetland and non-wetland clusters]. The analysis quantifies the spectral distinction/overlap of signatures based on the defined distance algorithm Euclidean distance [value range 0-120]. Any value above 100 indicates best spectral separability while the value below 30 indicates spectrally similar classes [Chauhan, 2004].

The Euclidean distance (EC) between the “centres” of classes i and j with the mean vectors \((\bar{M}_i,\ldots,\bar{M}_{in})\) and \((\bar{M}_j,\ldots,\bar{M}_{jn})\), is calculated as [Bakonyi and Johnson.1995]:

\[
EC_{ij} = \sqrt{\sum_{x=1}^{n} (M_{ix} - M_{jx})^2}
\]

The analysis provides a group of ‘natural clusters’ to facilitate automated and semi-automated digital classification. Reconnaissance and the data collected during the ground survey (June-October, 2006) was of value in the identification of the ‘image/natural clusters’. These were later used as base points to amass test signatures for the classification process.

Further, the digital image was subjected to visual interpretation (using Arc-View) and unsupervised classification (using ERDAS) to test the response of multiple spatial classifiers. Using on-screen visual interpretation (based on visually deriving spectral information from different band combinations [543, 564, 432 and 563] of the Landsat image) broad vegetative and non-vegetative groups/sub-groups was delineated to derived a vector layer based on the elements of image-interpretation (tone, texture, colour, pattern, association). Visual interpretation is a subjective method and takes account of contextual information and the experience of the individual analyst. In such a case, the repetition of the process is difficult task even if the high accuracy of the result is promised. Considering this limitation, the natural clusters derived from the separability analysis was subjected to the iterative process of unsupervised approach based on Isodata clustering algorithm.

Class separation was started using 100 clusters, aggregated to 25 and finally to 8. In view of the restriction of automated approach to separate closely related vegetation communities, the image was further analysed using supervised classification approach.

The unsupervised approach provides base information to customise the supervised algorithm for wetland classification. The multi-spectral data was classified in ERDAS 9.2 [using maximum likelihood algorithm] to derive a disaggregated land cover/use having 25 classes. At this point, the ancillary information viz., road layer stream network, river and drainage, GPS track points and trace lines, field photographs and the population data was refereed for refinement (Tab. 1). Noted was an ambiguity in discriminating closely related wetland and non-wetland communities, Google Earth images were refereed for the refinement process and to resolve discrepancies. At a final point a reclassification process resulted in an aggregated semi-supervised output with eight land cover/use units.
Post classification ground survey along with support from the primary and secondary socioeconomic information (focal group discussions (FGD), natural resource consumption statistics, and industrial zone pattern) added to improve the classification accuracy. The process was repeated to generate temporal profiles for 1987, 1992 and 2002 images (land cover/use, wetland cover and settlement/built up area).

Table 1 - Spatial and ancillary data sets used in wetland mapping and change analysis process.

| Sensor                     | Resolution | Bands | Purpose                                                      |
|----------------------------|------------|-------|--------------------------------------------------------------|
| Landsat TM (1987, 1992, 2002) | 30 m       | 7     | to derive temporal layer of land cover (use) and wetland and built up areas |
| Landsat Geo-Cover          | 30m        | 4     | to refine ambiguities during the classification process       |
| Google Earth Images        | -          | -     | Verification and refinement of fuzzy areas in the classification process |

| Data set                  | Scale | Data Characteristics | Purpose |
|---------------------------|-------|----------------------|---------|
| Topographic survey maps   | 1: 50,000 | National and Provincial level | To delineate boundaries |
| Drainage map              | 1: 50,000 | National and Provincial level | To analyze water flow, input for change analysis |
| Road and Rail network     | 1: 50,000 | National Provincial and DS level Primary and Secondary network | To calculate proximity analysis in the change analysis model |
| Stream Flow               | 1: 50,000 | At divisional scale | Input for change analysis |
| Population density map    | 1: 50,000 | At divisional scale | Input for change analysis and to interpret stress indicators |
| Rainfall and humidity data | -     | monthly mean | To identify rainfall pattern (wet and dry) for spatial data selection and also validation of the flooding zones in spatial analysis |

Component 2: Change Detection Analyses for Muthrajawela marsh-Negombo lagoon

The change analysis module explains the application of LCM (land change modeller in IDRISI-Andes version) to understand the wetland dynamics of the coastal systems. The land cover/use base map produced during the first component of the analyses was subjected to change module (algorithms) in ERDAS viz. NDVI differencing, image subtraction and differencing and the product subtraction method. The result from these change detection models was evaluated for its ability to classify temporal states in the wetland ecosystem. The ‘image difference’ algorithm depicts the difference in the temporal images based on the spatial-contextual information incorporated in the neighbourhood of each pixel and provides a detailed picture of gradient of change based on whole image subtraction. The ‘unsupervised classifier’ algorithm on the other hand is an automatic technique that discriminates changed and unchanged pixels based on the mechanical selection of the decision threshold. This process minimizes the overall change detection, underneath the postulation that pixels in the difference image are independent of one
another and calculated the change in the landscape in terms of ‘increase’, ‘decrease’ and ‘no change’. The complexity in spatial analysis based changed detection of resource systems has been highlighted by many researchers, who suggested both data and techniques based approaches [Erener and Düzgün, 2009; Galante, 2009].

Eventually LCM (land change modeler-based on the Markov Random Fields (MRFs)- Ferreira and Oliveira, 2007) in IDRISI-Andes version is used to capture the wetland dynamics. LCM is a built-in extensive vertical application specific for natural resource management that utilises the inter-pixel class dependency concept. An integrated algorithm LCM, uses dynamic, nonlinear simulation trend analysis to calculate the total and net change; along with the in-depth analysis of interchange between different communities. The change analysis algorithm in LCM defines a set of tools for the rapid assessment of change, evaluation of gains and losses, estimation of net change both in the image and graphical form. The application was used to address the problem of accelerated land conversion and its link to change in wetland use in the coastal landscape of Sri Lanka. Various in-built modules in LCM viz ‘change analysis’ that provides a rapid quantitative assessment of change by graphing gains and losses of the individual land cover category; ‘net change’ that reflect the result by adding the gains and then subtracting the losses and the ‘contributions to change’ module was tested.

In terms of the supporting socioeconomic phase of the study the secondary data was collected at Grama Niladari [GN] level to complement the biophysical geospatial analysis. A survey form [based on the sustainable livelihoods (SL) framework] that include the relevant socioeconomic parameters for the geospatial model was designed for data collection, with a special focus on the five livelihood assets or capitals– natural, human, social, physical and financial capital (DFID, 2001). Additionally, detailed data (particularly to validate the result of the change analysis phase) was collected using socio-economic assessments methods that involves a combination of participatory methods (such as community mapping of village, wealth ranking exercises and focus group discussions) and a more conventional household survey covering livelihoods and environmental issues.

**Results**

**Wetland mapping and classification**

The separability analyses reflect that all water-related classes for example canal, lagoon, and inundated marsh have closely identical spectral signature. The performance of band 5, 4, 3 of Landsat image is summarized in Table 2.

The most recognizable difference (high value of spectral seperability) is between the marshland and the built up area. The DN values in Band 4 (infra red) of Landsat image show lagoon, marshland and paddy fields as clear clusters. The values in band 4 and 7 (thermal) reflect the function of vegetation and moisture in differentiating the wetland communities. The digital signatures of the wetland classes (marshland, littoral zone, deep water lagoon, shallow water body and others) differ from those of the non-wetland (built up areas, coconut grove, open fallow land) significantly. The built up area was particularly separable (with the Euclidean value of 77.7 with littoral, and 117.7 with lagoon) from vegetation. The shallow lagoon and small water bodies reflect the separability value as 1.2 (indicating poor seperability). The abandoned paddy field had high seperability value compared to open/fallow areas, but medium value compared with ‘other vegetation’ (open patches with shrub/grass). However, the seperability of abandoned paddy fields with shallow water body was not very distinct; clarified
by moisture retention of the paddy fields and their subsequent conversion into marshy area. The exercise provided an abbreviated view of distribution of wetland and non-wetland clusters in the coastal landscape. TM bands-543 showed the marshy areas in the image as dirty reddish green and these were classified using on-screen visual interpretation. The lagoon was delineated using image enhancement ratio and different band combinations [(561, 563), band ratio (4/3)]; the approach was subjective and not a complete win to capture the landscape complexity of coastal wetland, especially the sedimentation in the lagoon [possibly due to intermixing of spectral signatures]. The mangrove/littoral delineation was encouraging using the band combination of 563, 562 and 561 (Fig. 3b). In addition the built up area and the coconut groove reflected intermixing in signatures as was the case of paddy fields and open grasslands.

Table 2 - Separability analysis based on the Euclidean distances algorithm for 1987- Landsat TM (band combination 5 43) (highlighted separability distances are explained in the text).

| Land cover (use)       | Settlements/built up | Coconut groves with home garden | Marshland | Water body deep-lagoon | Small water bodies with vegetation | Canals | Shallow water body | Open areas | Other vegetation | Agriculture zone | Littoral zone-mangroves | Shrub land | Abandoned fields |
|------------------------|----------------------|---------------------------------|-----------|-------------------------|-------------------------------------|--------|-------------------|------------|-------------------|-----------------|------------------------|-------------|-------------------|
| Settlements/built up   | 0.00                 | 58.63                           | 72.63     | 117.65                  | 75.59                               | 75.78  | 74.67             | 26.00      | 64.15             | 30.86           | 77.72                  | 58.01       | 55.83             |
| Coconut groves with home garden | 58.63 | 0.00                           | 17.81     | 85.16                   | 36.55                               | 40.15  | 36.58             | 79.30      | 12.27             | 36.46           | 19.10                  | 9.83        | 33.65             |
| Marshland              | 72.63                | 17.81                           | 0.00      | 70.23                   | 24.05                               | 28.43  | 24.58             | 94.34      | 8.55              | 52.57           | 13.08                  | 15.23       | 31.73             |
| Water body deep-lagoon | 117.65               | 85.16                           | 70.23     | 0.00                    | 49.15                               | 46.58  | 49.40             | 73.33      | 111.65           | 80.46           | 78.17                  | 64.20       |                   |
| Small water bodies with vegetation | 75.59 | 36.55                          | 24.05     | 49.15                   | 0.00                                | 4.68   | 1.24              | 99.06      | 24.74             | 63.76           | 36.67                  | 29.06       | 21.38             |
| Canals                 | 75.78                | 40.15                           | 28.43     | 46.58                   | 4.68                                | 0.00   | 3.97              | 99.22      | 28.50             | 65.42           | 41.19                  | 32.18       | 20.52             |
| Shallow water body     | 74.67                | 36.58                           | 24.58     | 49.40                   | 1.24                                | 3.97   | 0.00              | 98.15      | 24.86             | 63.18           | 37.31                  | 28.93       | 20.26             |
| Open areas             | 26.00                | 79.30                           | 94.34     | 141.46                  | 99.06                               | 99.22  | 98.15             | 0.00       | 85.93             | 44.68           | 98.11                  | 79.22       | 78.92             |
| Other vegetation       | 64.15                | 12.27                           | 8.55      | 73.33                   | 24.74                               | 28.50  | 24.86             | 85.93      | 0.00              | 44.80           | 18.15                  | 7.04        | 26.08             |
| Agriculture zone       | 30.86                | 36.46                           | 52.57     | 111.65                  | 63.76                               | 65.42  | 63.18             | 44.68      | 44.80             | 0.00            | 54.42                  | 37.98       | 48.21             |
| Littoral zone-mangroves| 77.72                | 19.10                           | 13.08     | 80.46                   | 36.67                               | 41.19  | 37.31             | 98.11      | 18.15             | 54.42           | 0.00                   | 22.54       | 43.92             |
| Shrub land             | 58.01                | 9.83                            | 15.23     | 78.17                   | 29.06                               | 32.18  | 28.93             | 79.22      | 7.04              | 37.98           | 22.54                  | 0.00        | 24.94             |
| Abandoned fields       | 55.83                | 33.65                           | 31.73     | 64.20                   | 21.38                               | 20.52  | 20.26             | 78.92      | 26.08             | 48.21           | 43.92                  | 24.94       | 0.00              |

Figure 3c show the classified output from the unsupervised classification. The process started by defining 50 class disaggregated layer that was aggregated into 8 classes as shown in Table 3; with clear delineation of the lagoon and water bodies. Signature mixing caused difficulty in accurately classifying the littoral vegetation and the dense coconut grove (home-garden). Differentiating marshland from the moist shrubby areas and small water body from the shallow canal was somewhat uncertain. The supervised classification spanned three disaggregated phases
(thematic layers with 25, 18 and 15 classes), to an aggregated classified image (Google image supported refinement) with nine land cover/use units (Fig. 3f). The kappa value of disaggregated image (25 classes) is noted as 76 % and of final classified image (9 land cover units) as 87%. Noted was indecision in separating marshland with shrubs from open moist area with shrubs (Tab. 3). Comparing the accuracy of different clarification approaches, a high degree of spectral confusion was noted while classifying the coastal wetland; predominant in automated classifiers and relatively less in the visual method.

**Table 3 - Accuracy of different classification methods for 1987 and 1992 data.** The accuracy was calculated using self-generated random points, topographic maps, and socioeconomic data. The total number of GCP (ground control points) used is 57.

| Classification approach | Software Used                        | land cover (use) units | Wetland cover | Accuracy (%) |
|-------------------------|--------------------------------------|------------------------|---------------|--------------|
| Unsupervised classification | ERDAS 9.0 (GLT)                  | 23                     | 6             | 70.62        |
| Supervised classification | ERDAS 9.0 (GLT)                  | 17                     | 7             | 78.23        |
| Visual Interpretation   | Arc View (3.2)               | 11                     | 7             | 83-56        |
| Knowledge Classifier/Hybrid classification (Semi-supervised) | ERDAS 9.0 (GLT), refinement in IDRISI- Andes | 9                      | 9             | 86.5         |

**Figure 3 - Spatial data analysis for wetland cover delineation illustrating different classification approaches.**

**Wetland Change Analyses**

The disaggregated product from ‘image difference’ algorithm shows interchange and transition in communities at pixel scale making it difficult to infer at landscape level (Fig. 4a) also explained by Long and Yang, [1990] and Chang et al., [2005]. Whilst, the ‘unsupervised
classifier’ algorithm based analysis depicted broad ‘increase’ or ‘decrease’ zones that could not explain the interchange between different wetland units.

Overall both methods are subjective and reliant on on threshold definition by the user (Fig. 4b). Figure 4c displays the simulation outcome of the LCM (attained by defining different thresholds) algorithm. Significant changes in wetland cover/use pattern between 1987 and 2002
are noted: a) The conversion of the lagoon into shallow sediment laden water body b) the change of marshland into built up area/ settlements are the most prominent (Fig. 5).

Table 4 - Land cover (use) and wetland areas delineated using refined semi-supervised classification and surveyed transition.

| Land cover/ (use)                  | Type of System | Wetland | Area (Ha) | Change | Transition/ Change                                                                 |
|-----------------------------------|----------------|---------|-----------|--------|-----------------------------------------------------------------------------------|
| Sandy Beach (tourism)             | Natural        | yes     | 354.7     | 374.9  | 469                                 | Increase in natural system over tidal effects and tsunami after effect |
| Shrubland (grazing)               | Semi-natural   | no      | 862.85    | 809.3  | 698.3                               | Decrease in scrublands around the settlement zones partially due to encroachments |
| Lagoon (fishing)                  | Semi-natural   | yes     | 2557.7    | 2328.4 | 1954.3                              | Increase in sedimentation has resulted in shallow water system          |
| Littoral vegetation (fuel and fodder) | Semi-natural   | yes     | 522.8     | 708.9  | 761.4                               | Naturalised to semi-naturalised vegetation                              |
| Coconuts (home gardens)           | Modified       | no      | 1580.5    | 1425   | 1753.4                              | Increase in modified systems                                           |
| Grassland (abandoned paddy)       | Semi-natural   | yes     | 1417.1    | 1640.3 | 732.6                               | Modified into semi-naturalised (abandoned paddy to marsh)               |
| Grasslands (paddy with other crops) | Modified       | yes     | 1301.3    | 747.6  | 369.7                               | Decrease in modified system                                             |
| Marshland (grazing)               | Semi-natural   | yes     | 933.3     | 1181.7 | 971.3                               | Modified into semi-naturalised (abandoned paddy to marsh)               |
| Shallow water (domestic use)      | Semi-natural   | yes     | 1081.6    | 708.4  | 1074.3                              | Fluctuation in the system over canal blockage and increase in sedimentation in the Lagoon |
| Built-up (settlements and industrial) | Modified     | no      | 1002.3    | 1684.6 | 2815                                | Increase in modified system                                             |
The change in the areal extent of agricultural land was significant from 1987-1992 [as the result of conversion of agriculture land to abandoned fields, driven by increased salinity [Nagabhatla et al., 2007] (Tab. 4). Another key change in the wetland landscape was observed between 1992 and 2002, as of growing industrial/free trade zone; that had originally developed along the peripheral zone of marshland and later began to expand exponentially (Fig. 5).

In Table 5 it is made clear how a particular land cover (wetland) type contributes to net change. Detailed statistics of change from one land cover (use) to another over the past decade was also analysed with selected examples shown in Table 6 and an aggregated map in Figure 5. Significant changes (1987-2002) include (i) decrease in deep water lagoon area (4.5%) (ii) shrinking of littoral forest (1.8 %) and marsh (1.3%) and (iii) expansion in built up area. Overall, LCM provides important observations in terms of area transitions, net change and the contribution to change by each land cover unit (Fig. 6). The study endorses the role of multi-scalar and temporal earth observation data and geospatial techniques for wetland characterisation.
Table 6 - Fraction of the total analysis of recorded change of one land cover/use to another (for 1992-2002) analysed using net change module in IDRISI (LCM).

| Land cover/use                      | From                              | To                        | Change in area (Ha) | Change (%) |
|------------------------------------|-----------------------------------|---------------------------|---------------------|------------|
| Home garden with Coconut           | Marshy area with shrubs           | Open Areas/Fallow         | 68                  | 0.7        |
| Littoral Vegetation                | Marshland                         | Marshy mudflats           | 97                  | 1.0        |
| Marshland                          | Grassland (abandoned paddy)       | Open Areas/Fallow         | 72                  | 0.7        |
| Shallow Water with Sediments       | Littoral Vegetation               | Home garden with coconut  | 56                  | 0.6        |
| Littoral Vegetation                | Home garden with Coconut          | Built-up/ Settlements    | 122                 | 1.3        |
| Marshland                          | Agriculture with other Vegetation  | Home garden with coconut  | 229                 | 2.5        |
| Grassland (abandoned paddy)        | Marshland                         | Home garden with coconut  | 574                 | 6.2        |
| Agriculture with other Vegetation  | Marshland                         | Home garden with coconut  | 250                 | 2.7        |
| Littoral Vegetation                | Marshland                         | Shrub land                | 157                 | 1.7        |
| Marshland                          | Marshland                         | Littoral Vegetation       | 346                 | 3.7        |
| Grassland (abandoned paddy)        | Shallow Water with Sediments      | Scrubland                 | 287                 | 3.1        |
| Home garden with Coconut           | Littoral Vegetation (Mangrove, Shrubs...) | Built-up/ Settlements | 161                | 1.7        |
| Marshland                          | Agriculture with other Vegetation  | Built-up/ Settlements    | 561                 | 6.1        |
| Agriculture with other Vegetation  | Marshland                         | Shrub land                | 127                 | 1.4        |
| Home garden with Coconut           | Littoral Vegetation               | Marshland                 | 129                 | 1.4        |
| Littoral Vegetation                | Marshland                         | Marshland                 | 1385                | 15.0       |
| Built-up/ Settlements              | Grassland (abandoned paddy)       | Marshland                 | 236                 | 2.6        |
| Grassland (abandoned paddy)        | Built-up/ Settlements             | Marshland                 | 213                 | 2.3        |
| Paddy with Other Vegetation        | Grassland (abandoned paddy)       | Marshland                 | 134                 | 1.4        |
| Grassland (abandoned paddy)        | Water Body Deep Lagoon            | Marshland                 | 149                 | 1.6        |
| Shallow Water with Sediments       | Marshland                         | Water Body Deep Lagoon    | 168                 | 1.8        |

**Socioeconomics integrated with geospatial analysis**

A vital element of the study is coupling the geospatial observations with the socio-economic data. The primary socio-economic data collected at the village and household level supports the problems highlighted by the spatial analysis and helps to validate the spatial statistics (Tab. 7). This integration offers a method to map, monitor and assess (fine tune the change detection process) the dynamics of wetland system in a holistic way. For example: temporal analysis depicts
shrinking of marshland and the socioeconomic information verified this spatial observation. Further it could provide factors to explain the change; as members of the local community pointed out that increased anthropogenic pressure, process of infilling of marsh and growing encroachments are among the most important factors that resulted in the shrinking of the marsh. It was interesting to observe how the social communities in the wetland complex could confirm and support the observation made using spatial analysis. Respondents verified the major change in the landscape (from 1992-2002) reported from temporal analysis; the reasons for which could be traced to disturbance from waves and storms (micro-climatic variation, impact of tsunami), fall in agricultural activity (adverse impact on agriculture practice by salinity issues) and the anthropogenic transitions (especially due to expansion in settlement and industrial area).

The increase in the built up area was supported by secondary sources of socio-economic data (specifically the demographic data), key informant interviews and the focus group discussions held with local community members. There have also been natural transitions taking place in the wetland for example the abandoned paddy fields have naturalised over time into moist grasslands contributing a habitat for floral and faunal diversity. These environmental changes taking place within the wetland have also been observed and experienced by local communities as described in Table 7 and Figure 7. Overall, the above observations meant that the wetland landscape is a fragmented unit both ecologically and for the local communities accessing wetland services for their livelihoods. For example, sedimentation in the canal/lagoon have resulted in clogging the flushing mechanism and adversely impacted the water retention and salinity balance of the lagoon-marsh hydrological system, that further led to adversative impact on the fish productivity and in return on the income levels of fishers.

Figure 6 - Transitions in land cover (use) – different scenarios; (a) Change in marshland area, increase and decrease from 1987-1992; (b) Change in the built area (settlement and industrial belt), contribution by the other communities; (c) Change analysis loss and gain by category (% area from 1992 -2002.)
Table 7 - Validation of change analysis process using primary/secondary socioeconomic data.

| Change Indicators (spatial analysis in IDRISI) | Conversion (from and to) | Socioeconomic assessment | Comment |
|----------------------------------------------|--------------------------|--------------------------|---------|
| Sedimentation                                | Deep water body to shallow sediment areas | Data from Household survey and FGDs describing perceived environmental changes and impacts on livelihoods | Household level survey data; FGDs | The fishers were of the opinion that the decrease in depth of the lagoon had impacted the overall fisheries productivity. |
| Marshy Infilling                             | Marshy and swamp areas to settlement and encroached lands | Data from household survey on describing perceived environmental changes and impacts on livelihoods | Household level survey | A majority of survey respondents perceived the clearing of the marsh and the initiation of development activities in the area, as a change for the better as it had uplifted their living conditions. |
| Abandoned agriculture                        | Paddy fields to abandoned grasslands | Secondary sources of data and qualitative information from residents | Literature review and key informant interviews | Productive rice cultivation areas were established in the country, the irrigation department paid little attention to Muthurajawela and the rice cultivation was abandoned. |
| Siltation and blockage of canals             | Fresh water irrigation canals to stagnant shallow water patches | Data from household survey and FGDs on describing perceived environmental changes and impacts on livelihoods | Household level survey data; FGDs | Have adversely effected the flush mechanism and the salinity control mechanism of the lagoon |
| Encroached and degraded littoral zones       | Primary mangrove and coastal vegetation to mangrove associations and encroached areas | Data from household survey on problems linked to accessing natural resources | Household survey data | The mangrove areas had been degraded as some residents cut down the mangroves to use for fire wood |
| Increased built up areas                     | Conversion of wetland communities to industrial and settlement zone | Population statistics at different management scale --village level, district and GN level | Literature review to collect secondary sources of data using a field form | Expanding population and increase industrialization and development in the area due to close proximity to the industrial zone and the international airport. |
| Shrinking agriculture activities             | Natural degradation of agricultural lands to marshy swamp areas | Secondary sources of data viz., number of families dependent on natural resource usage | Literature review | Rice cultivation areas were established in the country, the irrigation department paid little attention to Muthurajawela and subsequently rice cultivation was abandoned. |
Figure 7 - The primary socioeconomic analysis (dependence on natural resource/natural resource consumption pattern at DS level) validates lagoon pollution and sedimentation activity supported by reduction in fishing as a livelihood activity (in inset). Focal group discussions confirmed and validated major analysis results viz, loss of depth / lagoon sedimentation, mangrove forest fragmentation.

Conclusion
The study adds to the understanding that wetland delineation and mapping in coastal regions is an arduous task, particularly to differentiate and classify closely related vegetation communities for example seasonally inundated open areas from marshlands with sparse or no vegetation. The first section of the study tests a range of spatial classifiers and evaluates their accuracy in classifying coastal wetlands. Separability analysis results in pixel clustering complementing the spatial classification. It was observed that visual interpretation approach provides a comprehensive overview of the wetland cover, yet it offers less opportunity to understand the in-depth stratification in coastal wetland use. Unsupervised classification approach was not considerably successful in differentiating closely related vegetation communities (viz., marsh areas with shrubs and open wet areas with grass and shrub patches). Supervised classification reflect comparatively better result to separate spectrally similar communities such as marsh area with grass patches and the grass interspersed seasonally inundated open area with more confidence (as classifying the image using test signature improved the certainty). Eventually, wetland cover was geospatially analysed using the supervised classifier with an accuracy of 87%. The study reflects an approach for practical application of pro-supervised learning and pattern recognition for the multi-spectral earth observation data. This ergonomic approach can be interactively manipulated, modified and refined for wetlands of similar type.

The second component describes wetland dynamics including the accelerated land conversion in the wetland complex using LCM. The spatial pattern of change coupled with the socio-economic information explains that the landscape was suitably intact till 1987 as the irrigation channels governed the water flushing and salinity of the lagoon. In 1992,
the marsh area was declared as a wetland sanctuary. At the same time, the region experienced increased incidence of climatic extreme events primarily rainfall (trends in rainfall during the time is reflected in Figure 2) and change in soil properties (due to influx of saline water from irrigation canals) that adversely impacted the surrounding agriculture (cultivated paddy). The paddy fields were abandoned and progressively converted into a marshland interspersed with grass/shrubby species such as *Typha augustifolia* and *Phragmites karka* [refer 2000 image analysis]. Subsequently, the increase in economic expansion activities towards the southern end of the lagoon led to enlarging the built-up (industrial/ settlements) area contributing towards the sediment load draining in canals and the lagoon. The process over years resulted in canal blockage, disturbed fresh water flow and reduced retention capacity of the lagoon, hence adversely affecting fish productivity and the livelihood dependence of local communities.

In principal, the study underlines an approach to simulate land use change using an integrated geospatial approach. The application of socioeconomic data to derive useful information on structure and dynamics of coastal wetland systems supplemented and validated the spatially derived wetland assessment. We contend that a) socioeconomic information considerably improved the accuracy of mapping over parametric classification and b) IDRISI [LCM] module provides a good platform to understand the resource dynamics. Both observations are crucial towards a sustainable management planning of wetland systems.

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