Monitoring Mangrove Plantation along the Coastal Belts of Bangladesh (1989-2010)

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Abstract

Mangroves are important coastal ecosystems and are located at the inter-tidal zones of tropical and sub-tropical belts. The global mangrove forests are declining dramatically because of the conversion of forests to shrimp farming, over-exploitation, pollution and freshwater diversion. The Bangladesh Forest Department initiated mangrove afforestation throughout the coastal belts of Bangladesh in 1966 to provide better protection for the coastal communities. Up to 1990, 120,000 ha of mangroves had been planted and it is one of the largest coastal afforestation programs in the world. The objective of this study is to exploit the spatial extent of mangrove plantation and their dynamics of changes over the last two decades using multispectral Landsat imagery. The study area covers the coastal areas of Bangladesh that is extended over the eastern part of SundaRBans up to Teknaf, the southern tip of mainland Bangladesh. Mangrove plantations were interpreted visually on computer screen and interactive delineation of forest boundary was done. The mangrove plantation area has been estimated as 32,725, 47,636 and 43,166 ha for the year of 1989, 2000 and 2010, respectively. Mangrove deforestation by human activity has increased almost six times in the recent decade in comparison to the previous one. The mangrove forest loss due to coastal erosion has slightly declined in the 2000s. Mangroves have been lost primarily because of agricultural expansion. The result of this investigation will be helpful to understand the dynamics of mangrove plantation and the main drivers of changes in this coastal ecosystem.

Key Words: mangroves, landsat, interactive visual interpretation, mapping, change detection

Background

Mangroves are located at the coastal and inter-tidal zones of tropical and sub-tropical belts and offer a great number of goods such as timber, pole, firewood, food (i.e. honey), industrial raw materials (i.e. softwood for match industry, pulp and paper), salt, tannins and other miscellaneous products (thatching hut). Numeric rivers, channels, creeks, marshy lands in mangrove ecosystem are used by fish, prawn and shellfish as nurseries and feeding habitats (Lugo and Snedaker 1974; Field et al. 1998). Mangrove swamps provide a wide range of ecosystem services such as sediment trapping, nutrient recycling, retention of water and protection of shorelines from erosion (Lugo and Snedaker 1974). Moreover, mangroves serve as a natural barrier against storm surges and tsunamis (Das and Vincent 2009). Mangroves act as a crucial habitat for a variety of terrestrial and aquatic fauna (Nagelkerken et al. 2008). Mangroves have been discovered recently as one of the most carbon rich forests on the earth (Donato et al. 2011). In addition, mangroves have important aesthetic, historical and cultural values (Gilbert and Janssen 1998; Rist and Dahdouh-Guebas 2006) and can be used in tourism.

Many mangroves are located along the coasts of devel-
oping countries where the rate of population growth and pressure on forests are high (Alongi 2002). Worldwide, the extent of mangrove forest is declining in area dramatically (Field 2000). A global reduction of mangrove about 25% has been observed since 1980 and the mangrove area today is less than 15 million ha (FAO 2007). The total area of mangroves is estimated to be 15.6 million hectares in 2010, down from 16.1 million hectares in 1990 (FAO 2010). The primary causes for the reduction of mangroves are conversion to shrimp farming, over-exploitation of resources, pollution and freshwater diversion (Field 2000, Linnweber and de Lacerda 2002, Barbier and Cox 2003).

The coastal areas of Bangladesh are often affected by severe cyclone and storm surges. The Bangladesh Forest Department initiated mangrove afforestation on the outside of the protective coastal embankments in 1966 to provide greater protection for the inhabitant of coastal areas (Saenger and Siddiqi 1993). The plantation activity expanded by World Bank aided mangrove afforestation project. From July 1980 to December 1985, the Phase I aimed to plant approximately 8,100 ha (20,000 acres) of mangroves annually while Phase II was designed to create a further 8,100 ha of new plantations annually from 1986 to 1990. By 1990, 120,000 ha of mangroves had been planted (Saenger and Siddiqi 1993). The plantation is one of the largest coastal afforestation programs in the world (Blasco and Aizpuru 2002).

These mangrove plantations developed along the coastal regions of Bangladesh are undergoing changes due to extreme population pressure and natural causes. The geomorphic processes in the Ganges-Bhramaputra Delta are active and there are often erosion and accretion by the natural process. Therefore, accurate delineation of mangroves and the changes in mangrove forest cover are important. The objective of this investigation is to delineate the changes in mangrove plantation throughout the coast of Bangladesh over the last decades and identify the major drivers in the change process. In this context, this article aims to exploit the spatial extent of mangrove plantation and their dynamics of changes over the last two decades using multispectral Landsat imagery. The study areas is located in the coastal areas of Bangladesh and extended over the eastern part of Sundarbans up to Teknaf, the southern tip of mainland Bangladesh.

Remote Sensing for Mangrove Vegetation Studies

Remote sensing can play a crucial role to map and monitor mangroves and their changes over a period of time. Mangrove mapping has been done using aerial photographs (Manson et al. 2001; Hossain et al. 2009); satellite remote sensing using Landsat (Vasconcelos et al. 2002; James et al. 2007; Giri et al. 2008; Rahman et al. 2013) and SPOT (Vits and Tack 1995; Manson et al. 2001; Liu et al. 2008; Lee and Yeh 2009) imagery have also been utilized extensively for mangrove forest mapping. In addition to optical remote sensing, Synthetic Aperture Radar (SAR) data has been used for mangrove vegetation studies (Kovacs et al. 2013).

Different image analysis methods have been used for mangrove mapping and change analysis. Visual interpretation (Gang and Agatsiva 1991; Murray et al. 2003; Fromard et al. 2004), vegetation index (Blasco et al. 1986; Jensen et al. 1991), unsupervised classification (Vits and Tack 1995; Murray et al. 2003; Bhatt et al. 2009), supervised classification (Dutrieux et al. 1990; Vits and Tack 1995; Aschbacher et al. 1995; Giri et al. 2007; Thu and Populus 2007), band ratioing (Populus and Lantieri 1991; Long et al. 1994; Rahman et al. 2013), hybrid classification (Giri et al. 2008; Hossain et al. 2009), object based classification (Conchedda et al. 2008) and other techniques have been used in the mapping of mangroves in different parts of the world.

The advancement of mangrove studies using remote sensing was summarized by Green et al. (1998), Heumann (2011) and Kuenzer et al. (2011). Most of the studies used various forms of digital classification techniques. Only a few investigations (i.e. Conchedda et al. 2008) considered object based classification technique where contextual information was analyzed in addition to pixel level spectral information. Gao et al. (2004) used a knowledge based approach to discriminate mangroves in the Waitemata Harbor of Auckland, New Zealand from other coastal vegetation using SPOT image. The study reported that mangroves are difficult to map accurately because of their spectral similarity to other coastal vegetation. The classification accuracy of pixel based approach increased sharply when spatial knowledge was combined with spectral information in map-
ping activity. In this study, an Interactive Visual Interpretation (IVI) technique was used where other information (i.e. size, pattern, association etc.) was integrated in addition to the pixel value in satellite image interpretation and classification procedures (MacSiurtain and Collins 1992).

**Methodology**

The study area is covered by four Landsat scenes (Table 1). These Landsat images (Level 1T; precision and terrain corrected) were downloaded from the United States Geological Survey (USGS) website. Cloud-free scenes could be obtained, except one that is partially covered by cloud concentrated outside the study area. The Landsat scenes used in this study fitted geometrically well for further analysis.

The Landsat scenes in different band combinations were inspected on computer screen in order to define the most suitable band combination for visual image interpretation and classification. TM bands 4, 5 and 3 visualized in the red, green and blue channels, respectively were found to be the most appropriate band combination for mangrove mapping. In the above band combination, mangrove plantations appear in dark red, water in blue and other land in different tones.

Mangrove and some other vegetation (i.e. homestead forests) appeared in similar color on a Landsat scene. However, mangrove could be separated from other vegetation using supporting information such as pattern, association and size. The patterns of distribution of mangrove plantation and homestead forest are different. Homestead vegetation is distributed following a specific pattern associated with the settlements. Mangrove plantations are usually distributed close to sea and river channels. Furthermore, the size of mangrove plantation is usually larger than homestead forests.

Mangroves could be separated from agricultural vegetation like paddy using color and texture. The color of paddy crops is lighter and the texture is finer than the color and texture of mangrove on a Landsat scene. The separation of paddy crops from other permanent vegetation becomes easier if multi-temporal satellite images are used. This crop has a short life cycle with duration of few weeks. The mapping of mangrove plantation, water and other land cover classes (described in Table 2) was done on-screen using the interactive visual interpretation (IVI) technique for the delineation of forest boundaries.

Forest and forest boundaries were delineated based on the spectral, textural and other contextual information. Other Landsat band combinations were tested to improve

<table>
<thead>
<tr>
<th>Year</th>
<th>Landsat scene frame/path</th>
<th>Sensor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>136-044</td>
<td>Thematic</td>
<td>12 Jan 1989</td>
</tr>
<tr>
<td></td>
<td>136-045</td>
<td>Mapper (TM)</td>
<td>05 Jan 1989</td>
</tr>
<tr>
<td></td>
<td>137-044</td>
<td></td>
<td>12 Jan 1989</td>
</tr>
<tr>
<td></td>
<td>137-045</td>
<td></td>
<td>28 Jan 1989</td>
</tr>
<tr>
<td></td>
<td>136-045</td>
<td>Thematic</td>
<td>07 Feb 2001</td>
</tr>
<tr>
<td></td>
<td>137-044</td>
<td>Mapper Plus</td>
<td>24 Nov 1999</td>
</tr>
<tr>
<td></td>
<td>137-045</td>
<td>(ETM + )</td>
<td>28 Feb 2000</td>
</tr>
<tr>
<td>2009-2010</td>
<td>136-044</td>
<td>Thematic</td>
<td>08 Feb 2010</td>
</tr>
<tr>
<td></td>
<td>136-045</td>
<td></td>
<td>06 Dec 2009</td>
</tr>
<tr>
<td></td>
<td>137-044</td>
<td></td>
<td>30 Jan 2010</td>
</tr>
<tr>
<td></td>
<td>137-045</td>
<td></td>
<td>30 Jan 2010</td>
</tr>
</tbody>
</table>

**Table 2. Description of various land cover categories considered in Landsat image interpretation**

<table>
<thead>
<tr>
<th>Land cover categories</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove plantation</td>
<td>Hydrophilic and halophytic vegetation, normally homogenous, composed mainly by <em>Sonneratia</em> species and <em>Avicennia</em> species, located along the coastal belt and tidal flats</td>
</tr>
<tr>
<td>Other land</td>
<td>Agricultural land: Land used for intensive agricultural production. Paddy cultivation in once, twice or thrice in a year. Part of the land is used for vegetable cultivation in winter months. Homestead vegetation: Mixed species of trees and vegetables planted around homesteads. Fallow land: Land not used in agricultural or other production. Urban: Cities and land covered by impervious surface.</td>
</tr>
<tr>
<td>Water</td>
<td>Sea, rivers, closed or open water bodies</td>
</tr>
</tbody>
</table>
the interpretation results and to avoid interpretation errors. The digitized forest boundary was overlaid on the satellite images of the different time periods in order to consistently define the change polygons.

The interpretation and delineation of mangrove forest boundary was started from the most recent image (2010). The entire mangrove plantation in the coastal regions of Bangladesh was digitized. The minimum mapping unit was defined as 1 ha. Then the 2010 vector layer was overlaid on the Landsat frames of 2000 (1999-2001). The identified changes were updated on the vector map keeping the earlier boundaries drawn on 2010 images unchanged and the layer was saved as change map (2000-2010). The appropriate land cover class was assigned to every individual polygon in the change layer both for recent and historical time. The changes are identified as mangrove afforestation (planted in bare land or newly accreted land) and deforestation (mangrove deforested by anthropogenic activities and mangrove lost by coastal erosion). The mangrove areas not changed in that time have been considered as stable. Similarly, a change vector layer was generated for the 1990-2000 time-frame and the appropriate identification for the polygons was assigned. The map of mangrove plantation (2010) was validated during the field-trips of 2011-2012. Field verification was done with the printed raw satellite image containing the digitized forest boundaries and portable GPS. Photographs were taken in the verified sites of mangrove plantation to check and validate the interpretation and classification results. Fig. 1 shows selected photographs collected during field verification.

Results and Discussion

Plantation interpretation and mapping

Mangrove monocultures dominated by Keora (*Sonneratia apetala*) appear in dark brown when Landsat bands 4, 5 and 3 are visualized in RGB (Fig. 2). Mangroves are clearly separable from other land and water. The other land consists of a variety of land cover classes including agriculture land, homestead vegetation, fallow land, urban etc. (Table 2).

Mangrove forest change for 1989-2000

The changes in mangrove plantation area for 1989-2000 are presented in the change map (Fig. 3a) and change ma-
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Fig. 2. Mangrove plantation and their appearances on Landsat image (band 4, 5 and 3 in RGB). A: Mangrove plantation, B: Other land (bare land) and C: Other land (tidal mudflats).

the vegetation change matrix represents the origin and destination for each individual land cover class.

The change matrix of 1989-2000 shows that forest has been expanded from 32,725 ha to 47,636 ha during this time. Afforestation activities took place on other land (12,064 ha) and water (7,167 ha). The conversion of the water class to plantation relates to mangrove afforestation on newly accreted land. Simultaneously, deforestation has also taken place in other locations; 1,863 ha of mangrove plantation have been converted to other land and anthropogenic factors are the main drivers of this change; forest has been lost for agricultural expansion. Other land is primarily used for seasonal cropland. Forest was also lost by natural factors; 2,458 ha of plantation has been eroded and washed away during this time.

Mangrove forest change matrix (Table 3). The change map of 1989-2000 contains 1,511 polygons. The vegetation change matrix represents the origin and destination for each individual land cover class.

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Mangrove forest change for 2000-2010

Changes in mangrove plantation for 2000-2010 are presented in Table 4 and Fig. 3b. The change map of 2000-2010 contains 1,350 polygons. Mangroves have been declined from 47,636 to 43,166 ha in the period. Forest has been lost to other land (11,204 ha) primarily because of the anthropogenic activities; conversion of forest to agricultural land. On the other hand, the loss of forest to water was 2,266 ha and it was driven by coastal erosion. Simultaneously, there was afforestation in some other places. Plantation has been expanded in other land (5,775 ha) and water (3,225 ha).

In order to understand the changes in mangrove plantation and underlying driving factors, the detailed changes were analyzed for two areas: Patharghata (Area A) and coastal regions of Noakhali (Area B).

Mangrove forest change in Site A (Patharghata region, 1989-2010)

Patharghata is located in the South-eastern part of Sundarbans. Satellite image analysis reveals that the area is eroding since 1973 though earlier change in coastal geomorphology of that area is not investigated in this analysis (Fig. 4). The coastline is gradually moving towards the north. The shoreline has been shifted to the mainland around 2 km in 1989-2010. The reason of coastline movement is currently unknown and it should be explored by further investigation.

The mangrove in Patharghata region was planted in be-
Table 3. Land cover change matrix for 1989-2000 (Area in ha)

<table>
<thead>
<tr>
<th></th>
<th>Forest</th>
<th>Other land</th>
<th>Water</th>
<th>Total (1989)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>28,405</td>
<td>1,863</td>
<td>2,458</td>
<td>32,725</td>
</tr>
<tr>
<td>Other land</td>
<td>12,064</td>
<td>2,067</td>
<td>29</td>
<td>14,160</td>
</tr>
<tr>
<td>Water</td>
<td>7,167</td>
<td>73</td>
<td>-</td>
<td>7,240</td>
</tr>
<tr>
<td>Total (2000)</td>
<td>47,636</td>
<td>4,003</td>
<td>2,486</td>
<td>54,125</td>
</tr>
</tbody>
</table>

Table 4. Land cover change matrix for 2000-2010 (Area in ha)

<table>
<thead>
<tr>
<th></th>
<th>Forest</th>
<th>Other land</th>
<th>Water</th>
<th>Total (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>34,166</td>
<td>11,204</td>
<td>2,266</td>
<td>47,636</td>
</tr>
<tr>
<td>Other land</td>
<td>5,775</td>
<td>118</td>
<td>39</td>
<td>5,932</td>
</tr>
<tr>
<td>Water</td>
<td>3,225</td>
<td>53</td>
<td>-</td>
<td>3,278</td>
</tr>
<tr>
<td>Total (2010)</td>
<td>43,166</td>
<td>11,374</td>
<td>2,305</td>
<td>56,846</td>
</tr>
</tbody>
</table>

Fig. 3. Delineation of changes in mangrove plantation along the coastal belts of Bangladesh for (a) 1989-2000 and (b) 2000-2010. Investigation at finer scale has been carried out in the selected two sites (Site A and Site B).

Investigation at finer scale has been carried out in the selected two sites (Site A and Site B).

between 1985-1989 (Anon 1993). The current study estimates the area of mangrove plantation 2,013 ha, 1,726 ha and 1,482 ha for the year of 1989, 2000 and 2010, respectively. Fig. 4 displays the changes in the coastal regions of Patharghata regions over 1973-2010. Mangrove forest loss by coastal erosion is 461 and 261 ha for the period of 1989-2000 and 2000-2010, respectively. The total loss of mangrove plantation is 722 ha (7.2 sq.km) during
the study period (1989-2010). On the other hand, the loss of mangrove forest due to anthropogenic causes is only 8 ha during 2000-2010. Forest was cut down by the people living in that region and it was converted to other land that is primarily used for crop production.

**Mangrove forest change in Site B (Coastal areas of Noakhali, 1999-2010)**

The mangroves planted in the coastal region of Noakhali have been disappeared in the 2000s (1999-2010) (Fig. 5). The plantation was raised in the 1980s, it remains stable in the 1990s, but rapidly disappeared in the 2000s (Fig. 3). The extent of plantation is estimated as 6,716 ha in 1999, 1,820 ha in 2003 and 781 ha in 2006; the total mangrove was deforested by 2010 (Table 5). The rate of forest clearing is 1,224 ha/year in 1999-2003, 346 ha/year in the 2003-2006 and 195 ha/year in the 2006-2010.

Field investigation revealed that the plantation was primarily lost because of the migration of landless people from the adjacent region. Many of the migrants lost their land by sea erosion and moved from the northern part of Hatia Island. They deforested the area by cutting down the trees, built their houses and used the neighboring land for agricultural purpose to support their livelihood (Fig. 1c). The

![Fig. 4. (a-c) The digitized forest boundary (1989-2010) (yellow color, in Black & White version appears in white) is overlaid on time-series Landsat images (1973-2010) in Patharghata. Mangrove forest appears in red to dark brown on Landsat band 4, 5 and 3 combinations.]

![Fig. 5. Pattern of deforestation in the coastal regions of Noakhali (1999-2010). Mangrove plantation appears in dark-red/brown (digitized forest boundary in black color).]

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (ha)</th>
<th>Time span</th>
<th>Total change (ha)</th>
<th>Period (years)</th>
<th>Change rate (ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>6,716</td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>2003</td>
<td>1,820</td>
<td>1999-2003</td>
<td>4,896</td>
<td>4</td>
<td>1,224</td>
</tr>
<tr>
<td>2006</td>
<td>781</td>
<td>2003-2006</td>
<td>1,039</td>
<td>3</td>
<td>346</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>2006-2010</td>
<td>781</td>
<td>4</td>
<td>195</td>
</tr>
</tbody>
</table>
Deforestation was not authorized by the Government and so it was not legal. Earlier, the land was transferred from the Ministry of Land to Bangladesh Forest Department to raise mangrove plantation. After the area has been deforested the land was transferred back to Ministry of Land. The occupants do not have the land titles.

Accuracy and sources of errors

The plantation statistics generated by this study were compared to the figures derived from the FAO project ‘Strengthening capacity to generate quality information on forest resources’. The forest cover map and statistics were generated at country scale for the years 2005-2006 within the framework of the project. According to these statistics, mangrove plantation was estimated as 47,585 ha for the coastal regions of Bangladesh (Islam 2007). The current study estimated the extent of mangrove plantation as 47,636 ha for 2000 and 43,166 ha for 2010. The figures of this study are in order of magnitude comparable to the figures from FAO.

In the Interactive Visual Interpretation (IVI) technique, the operator interprets and delineates land parcels and finally assigns an appropriate class ID. From Landsat satellite imagery, the basic land cover classes can be extracted well. The main sources of errors in this classification are therefore related to:

The size of land parcels

In Interactive Visual Interpretation (IVI), the minimum mapping size is visually judged by the interpreter. Errors may be associated with the accurate judgment of minimum mapping unit by the interpreter.

Low forest canopy density class

If forest canopy density is low, the assignment of a polygon to forest or non-forest cannot always be done unambiguously.

Forest fragmentation and polygons of mixed land cover

In a fragmented forest, it is often difficult to accurately delineate the forest boundary. Fragmented landscape also creates polygons of mixed land cover and the accurate assignment of a land cover class for such polygons is sometimes difficult. The mapping accuracy using IVI technique is reasonably high if the above situation does not exist in an area to be mapped.

Conclusion

Based on the study, it is concluded that the estimated mangrove plantation in the coastal regions of Bangladesh is 32,725, 47,636 and 43,166 ha for the year of 1989, 2000 and 2010, respectively. In total, the mangrove area has increased from 1989 to 2010 by about 10,500 ha due to intense government plantation programs. However, at the same time there was also a loss of plantation area. Mangrove deforestation by human activity has increased almost six times in the recent decade in comparison to the previous decade; mangrove plantations have been converted to agricultural land by the people living in the vicinity of the areas as well as by the migrants. The estimated deforested area is 1,863 and 11,204 ha, respectively in the study area for 1990s and 2000s. The mangrove forest loss because of coastal erosion is slightly declined in the 2000s; the estimated forest loss by coastal erosion is 2,458 ha and 2,266 ha for the year of 1989-2000 and 2000-2010, respectively. Forest loss by human activity can be mitigated by creating awareness among the local people. Mangroves raised through a participatory approach, involving local people with benefit sharing agreement might help to reduce deforestation activity by the anthropogenic drivers. In order to find the remedial measure to reduce forest loss by coastal erosion, further studies should be conducted.

The result of this investigation will be helpful to understand the dynamics of mangrove plantation and the main drivers of change process in this coastal ecosystem. The study has demonstrated that the technique of IVI is suitable for mapping and monitoring of mangrove forest, although it is time consuming when the areas are large and several monitoring periods are involved. Further study should be concentrated to explore suitable application method of forest mapping and change analysis by implying a shorter period of time.
Acknowledgement

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