

# Spatial and Temporal Changes of Sundarbans Reserve Forest in Bangladesh

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## ABSTRACT

Sundarbans, the largest mangrove chunk of the world is shared between Bangladesh (62%) and India (38%). The objective of this paper was to examine the spatial and temporal changes in land cover (forest cover area) of Sundarbans from 1973 to 2010 using remote sensing and geographic information system (GIS) tool. Normalized difference vegetation index (NDVI) was applied to calculate the density of vegetation of Sundarbans reserved forest (SRF). This study found that there were no major changes in total areas of SRF in the last 37 years (from 1973 to 2010) albeit changes were detected within the four land cover categories-water body, mudflat, barren land and vegetated land. During 1973 to 2010, water bodies, mudflats and barren lands increased by 0.45%, 19.69% and 14.81%, respectively, while vegetated land decreased by 4.01% during the same period. This indicated that the density of evergreen vegetation and its canopy closure decreased in Sundarbans. It was thus recommended that GIS and remote sensing based real time monitoring system be developed to identify spatial and temporal changes of land cover classes of SRF.

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## 1. INTRODUCTION

Mangroves are heavily used traditionally and commercially worldwide (Alongi, 2002). These forests are important land cover found in the tropics and subtropics regions of the world. Mangroves may grow as trees or shrubs according to the climate, salinity of the water, topography and edaphic features of the area in which they exist (FAO, 2007). These forests are also important for coastal ecosystems in terms of primary production and coastal environment protection. However, all over the world mangrove ecosystems are threatened with destruction through various forms of human pressure, in particular extraction, pollution and reclamation (Akhter, 2006). The mangrove areas worldwide have dropped to some 15.2 million hectares in 2005, down from 18.8 million hectares in 1980 (FAO, 2007). Therefore, it is important to assess the changes of mangrove forest cover for improved understanding on the gradual altering characteristics. Sundarbans mangrove forest is the largest and contiguous mangrove block of the world, has been gradually decreasing due to natural

processes and human interventions. Around 200 years ago, Sundarbans was around 16,700 km<sup>2</sup> (Banglapedia, 2015a) which is now dwindling down to half of its original size; the other half being cleared and converted to agricultural land (Hussain and Archarya, 1994). Therefore, the study of land cover classes is a very useful tool to identify spatial and chronological changes of Sundarbans mangrove forest.

The Sundarbans reserved forest (SRF) is the most economically valuable and the richest natural forests of Bangladesh which is blessed with enormous natural resources. Historically, these natural resources always engrossed people for diverse interests. This forest is surrounded by a very densely human populated area. These frontier people are mostly depended on Sundarbans for their livelihoods, therefore human pressure on the forest is important. Approximately 2.5 million people live in the small villages surrounding the Sundarbans, while the number of people within 20 km of the Sundarbans boundary is 3.14 million (MARC, 1995). SRF is free from any encroachment and

permanent human habitation except few hundreds of Forest Department personnel on official duty (IPAC, 2012). However, people like *Bawalis* (wood collectors), *Mouals* (honey or bee wax collectors), fishermen, mollusk shell collectors and grass cutters converged into the forest for extracting forest resources. Moreover, numerous people are also engaged in legal or illegal commercial exploitation of forest resources. The Sundarbans forest has been divided into three zones on the basis of salinity as follows: less saline zone (5-15 ppt) in eastern zone, moderately saline Zone (15-25 ppt) and strong saline zone (25-30 ppt) (CEGIS, 2006). The concentration of salinity in Sundarbans increases from east to west and, thus, density, vegetation growth and canopy closure decreases from east to west (Aziz and Paul, 2015). Level of salinity is also important determinant for height and growth of mangrove species (CEGIS, 2006; Hussain et al., 2013). For example, Sundari (*Heritiera fomes*) trees grows in low saline zone (5~10 ppt), Gewa (*Excoecaria agallocha*) in moderate saline zone (10-25 ppt) and Goran (*Ceriops decandra*) in high saline zone (over 25 ppt) (Hussain et al., 2013).

Sundarbans forest has lost its ecological diversity due to natural and anthropogenic causes (Islam, 2016). The productivity of the mangrove system had already declined by 25% in the two decades leading up 1985 (Chaffey et al., 1985). Sundari is the dominant floral species of the Sundarbans. But the abundance and dominance of Sundari tree in the forest has been decreasing because of 'Top-dying disease' (Banglapedia, 2015b). Around 20.18 million Sundari trees are seriously affected by this disease (Rahman, 1998). On the other hand, anthropogenic pressure on Sundarbans has been increasing in manifolds over the last few decades. These changes will have definite adverse impact on Sundarbans and lives and livelihoods of frontier population. Therefore, this research aimed to examine the spatial and temporal changes in land cover (forest cover area) of Sundarbans reserved forest from 1973 to 2010 using remote sensing and geographic information system (GIS) techniques to realize the contributing factors of Sundarbans land cover depletion.

Rahman et al. (2013) examined effectiveness of different classification methods for extraction of mangrove forest in Sundarbans using Landsat ETM+ data. Their study suggested that band

ratio/supervised classification approach produces the best accuracy in detecting the mangrove class. Bhowmik and Cabral (2013) studied on identifying the impact of cyclone Sidr on the floristic composition of Sundarbans using remote sensing method. This study identified a temporary lost of diversity (in terms of relative abundance) in affected three floristic taxa (*Heritiera fomes*, *Excoecaria agallocha* and *Sonneratia apetala*) of the Sundarbans after that severe exogenous perturbation; which took three years to regenerate.

The study of Rahman and Begum (2013) aimed to identify the spatial and temporal (during 1980 to 2009) dynamics of land cover and its impact on the ecosystem in Khulna and Satkhira districts in Bangladesh using GIS and remote sensing techniques. They found significant increase in homestead areas and water bodies, and decrease in fallow lands in their targeted study area. Their study did not find any remarkable change in mangrove vegetation.

Emch and Peterson (2006) in their study attempted to identify and compare change in results using the three image processing methods: normalized differential vegetation index (NDVI), maximum likelihood classification, and subpixel classification. The outcome of their study was both NDVI and subpixel classification revealed similar spatial distributions of areas that were deforested from 1989 to 2000 in Sundarbans. Islam (2014) studied on identifying the changes in vegetation cover of Sundarbans mangrove forest (both in Bangladesh and India) during 1975 to 2006 using Landsat imagery. Spatial changes were not identified even though huge population settled in the vicinity of the forest. The mangrove forest is decreased by 19.3% due severe tropical cyclone in 1977 and 1988. He concluded that future of Sundarbans depends to climatic issues e.g., salinity, frequency of severe tropical cyclone and tidal effect those directly depend to global warming.

A study was conducted by Resources Information Management System (RIMS) unit under Ministry of Environment and Forest, Bangladesh on 'Assessment of Sundarbans Reserved Forest in 1960, 1985, 1995 and 2013' (MoEF, 2014). This research described occupancy of different mangrove species in different years. The study found that areas covered by different forest types had been decreasing at an alarming rate. The

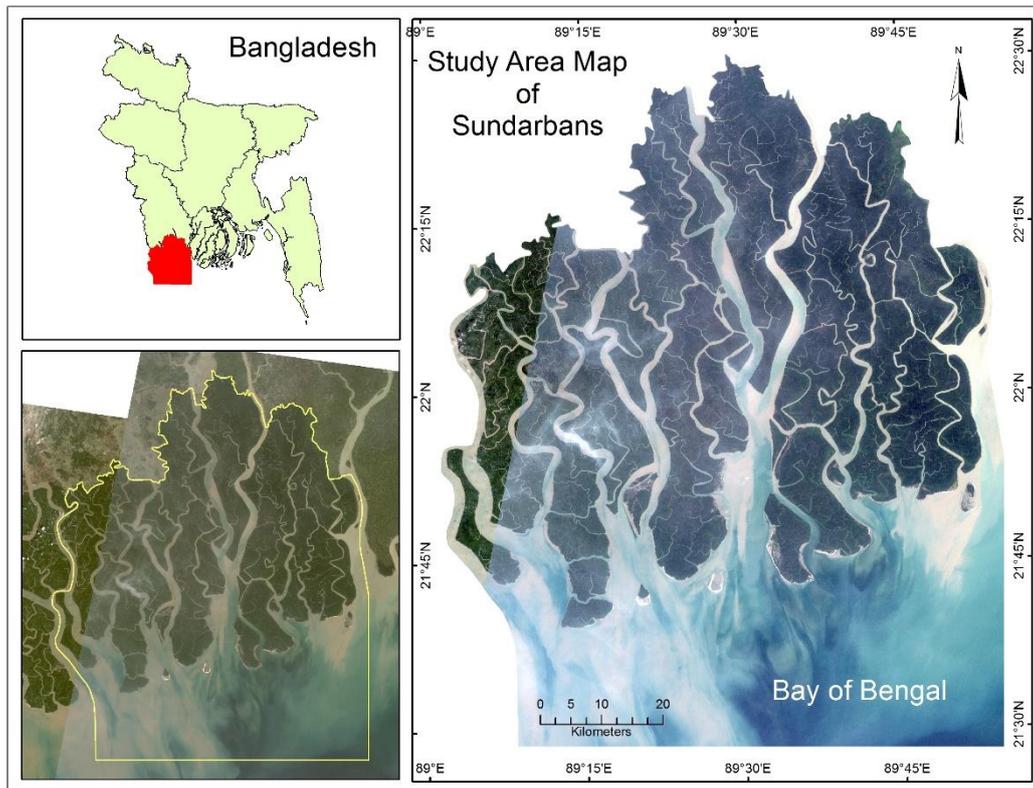
area occupied with Sundari tree was decreased by 24% in 2013 (74264 hectares) compared with 1960 (98551 hectares). The occupancy of Sundari-Gewa decreased from 123247 hectares in 1985 to 102274 hectares in 2013. In 1960, Sundari-Passur occupied around 29752 hectares forest cover. But, in 1985, this forest class reduced by 93%. Since then this Sundari-Passur tree cover remained more or less same with no further change. Moreover, similar pattern also observed for Sundari-Passur-Kankra. Sundari-Passur-Kankra forest type increased by 5% during 1985 (6799 hectares) to 1995 (7143 hectares) and decreased by 0.83% during 1985 (6799 hectares) to 2013 (7084 hectares). In contrast, the area of Gewa forest type increased by 70.85% in 2013 (21454 hectares) compared to 1960 (12557 hectares). Likewise, the area covered by Keora was

almost tripled in 2013 (10603 hectares) compared to 1985 (3509 hectares).

## 2. METHODOLOGY

### 2.1 Study area

Sundarbans reserve forest in Bangladesh is located at the edge of the southwest of Bangladesh between the Baleswar river in East and the Harinbanga river in west adjacent to the Bay of Bengal (UNESCO-WHC, 2016). Geographically, Sundarbans is located south of the Tropic of Cancer and lies between longitude 89°00'E and 89°55'E and latitudes 21°30'N and 22°30'N (Chaffey et al., 1985). The location of study area is shown in Figure 1. This study was conducted on the satellite imagery of Sundarbans reserved forest in Bangladesh.



**Figure 1.** Map of study area

### 2.2. Methodology of the study

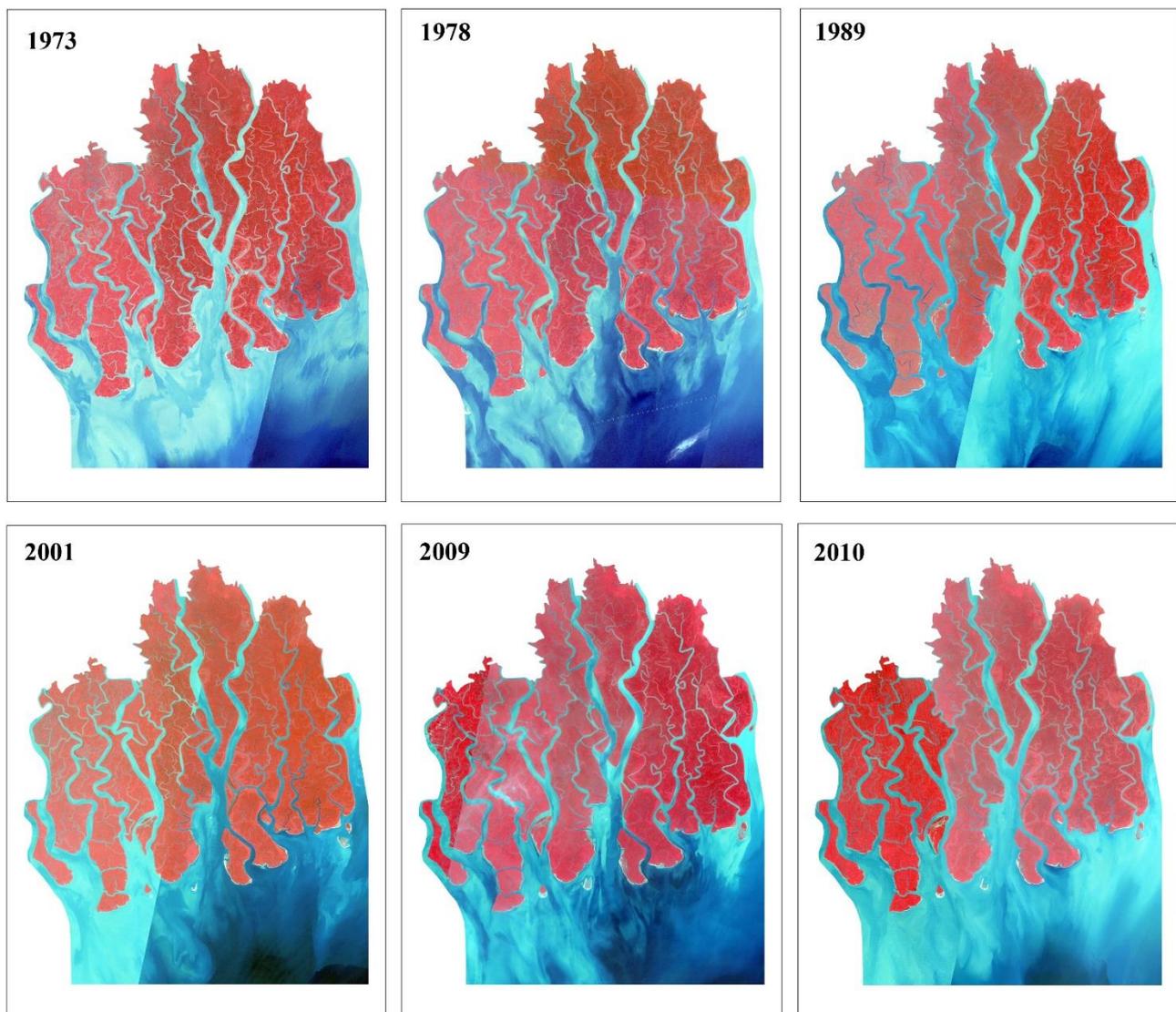
The study used Landsat images to derived chronological land cover maps. These images are provided historical records at free of cost. The study period was chosen from 1973 to 2010.

#### 2.2.1. Collection of Landsat images of study area

This study was conducted applying Universal Transverse Mercator (UTM) projected Landsat imagery from the Glovis. Images acquired in the months of November, December, January and February considering vegetation phenology, and less cloudy time periods of the year. Cloud free quality images are very important for analyzing land cover, hence actual study interval period was

compromised. Cloud free images were collected (except 2009 with 10% cloud cover) for this study. The Landsat images of SRF from 1973 to 2010 as shown in the Landsat images of Sundarbans in Figure 2. The actual acquisition dates of the images, spatial resolution and associated sensors that used in the study as shown in the properties of Landsat images in Table 1. Data from two sensors of

Landsat-multi spectral scanner (MSS) and thematic mapper (TM) used to derive land cover maps in satellite image. To visualize the images, blue, green, red and near-infrared bands were used for object identification. Two UTM Zone (45 and 46) projected data were downloaded from the data hub to cover SRF.



**Figure 2.** Landsat images of Sundarbans from 1973 to 2010 (Source: prepared from Glovis)

**Table 1.** Properties of Landsat images used in this study

Sensor type	Platform	Path/Row	Acquisition date	Spatial resolution (M)	Projection
MSS	LandSat 1	147/045	1973-02-02	80	UTM Zone 46
MSS	LandSat 1	148/044	1973-02-21	80	UTM Zone 45
MSS	LandSat 1	148/045	1973-02-21	80	UTM Zone 45

**Table 1.** Properties of Landsat images used in this study (cont.)

Sensor type	Platform	Path/Row	Acquisition date	Spatial resolution (M)	Projection
MSS	LandSat 2	147/045	1978-12-24	80	UTM Zone 46
MSS	LandSat 2	148/044	1978-12-25	80	UTM Zone 45
MSS	LandSat 2	148/045	1978-12-25	80	UTM Zone 45
TM	LandSat 4	137/045	1989-01-12	30	UTM Zone 46
TM	LandSat 4	138/045	1989-01-19	30	UTM Zone 45
TM	LandSat 5	137/045	2001-01-21	30	UTM Zone 46
TM	LandSat 5	138/045	2001-01-12	30	UTM Zone 45
TM	LandSat 5	137/045	2009-11-11	30	UTM Zone 46
TM	LandSat 5	138/045	2009-11-02	30	UTM Zone 45
TM	LandSat 5	137/045	2010-01-30	30	UTM Zone 46
TM	LandSat 5	138/045	2010-01-21	30	UTM Zone 45

Near Infrared (NIR) (0.7-0.8  $\mu\text{m}$  for MSS and 0.76- 0.90  $\mu\text{m}$  for TM) and Red (0.6-0.7  $\mu\text{m}$  for MSS and 0.63-0.69  $\mu\text{m}$  for TM) bands were used to detect the forest cover change in this study (USGS, 2016).

### 2.2.2. Image processing

ERDAS Imagine 2014 was used to perform digital images processing. This study used different bands (or layers) of information. Therefore, layers stacking were method was applied. Geometric Correction process used to co-registration the images as Bangladesh transverse mercator (BTM) projection. Histogram equalization was applied for clear visualization of the object in the images. To improve the quality of images, haze reduction tool was used. To calculate radiance from digital number (DN), the following formula was used.

$$L_{\lambda} = \frac{(LMAX_{\lambda} - LMIN_{\lambda})}{(QCALMAX - QCALMIN)} \times (QCAL - QCALMIN) + LMIN_{\lambda}$$

Where:

$L_{\lambda}$  = spectral radiance

QCAL = quantized calibrated pixel value in digital number

$LMIN_{\lambda}$  = spectral radiance scales to QCALMIN

$LMAX_{\lambda}$  = spectral radiance scales to QCALMAX

QCALMIN = minimum quantized calibrated pixel value

QCALMAX = maximum quantized calibrated pixel value

After that reflectance was calculated using the following formula (NASA, 2011):

$$pp = \frac{(\pi \times L_{\lambda} \times d^2)}{(ESUN_{\lambda} \times \text{Cos}\theta_s)}$$

Where:

$\rho_p$  = Planetary reflectance

$L_{\lambda}$  = Radiance at the sensor's aperture

d = Distance in astronomical units

$ESAN_{\lambda}$  = Solar exo-atmospheric irradiances

$\theta_s$  = Zenith angle in degrees

### 2.2.3. Image classification, NDVI calculation and map preparation

After careful visual interpretation, four categories of land cover class scheme were developed. These classes along with their descriptions as presented in the land cover classification scheme in Table 2. The images were limited to mangrove forest area and thus only four basic thematic classes were created: vegetated land, mudflat, barren land and water body.

Normalized difference vegetation index (NDVI) is calculated from the visible and near-infrared light reflected by vegetation. Thus NDVI can be determined: near-infrared reflectance ( $R_{NIR}$ ) minus visible reflectance ( $R_{RED}$ ) divided by near-infrared reflectance ( $R_{NIR}$ ) plus visible reflectance ( $R_{RED}$ ). Mathematically, the formula is (NASA, 2011):

$$NDVI = \frac{(R_{NIR} - R_{RED})}{(R_{NIR} + R_{RED})}$$

NDVI values ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero (NASA, 2011). A zero means no vegetation and close to +1 indicates the highest possible density of green leaves (NASA, 2011).

Using the conditional logic NDVI of the Landsat images were calculated and accordingly area covered by each category was calculated. The NDVI raster layer classified as water body, mudflat, barren land and vegetated land considering vegetation cover and forest types of Sundarbans

mangrove forest. Finally, land cover maps of 1973, 1978, 1989, 2001, 2009 and 2011 were prepared using Arc GIS 10.3. For accuracy assessment of land cover classes, this study used only high resolution areal images.

**Table 2.** Land cover classification scheme for this study

Land cover types	Description
Water body	River channels, rivulets and canals in Sundarbans
Mudflat	Wetlands in Sundarbans where tidal activities observed
Barren land	Exposed soils/sandy surfaces in Sundarbans
Vegetation	This includes all types of mangrove and non-mangrove forest cover of Sundarbans

### 3. RESULTS AND DISCUSSION

#### 3.1 Sundarbans land cover change: trend, rate and magnitude

NDVI spectral indices were calculated using Sundarbans study area subsets of 1973, 1978, 1989, 2001, 2009 and 2010 Landsat images and presented in Table 3.

During 1973 to 2010, barren land and mudflat of Sundarbans reserved forest increased, whereas, vegetated land decreased significantly. Rate of changes in land cover classes presented in Table 4.

**Table 3.** Summary of land cover classification statistics between 1973 and 2010 (area in hectares)

Land cover	1973		1978		1989	
	Area	%	Area	%	Area	%
Water body	411640.5	51.12	413009.4	51.29	412123.6	51.18
Mudflat	36397.01	4.52	39054.31	4.85	39617.98	4.92
Barren land	28264.05	3.51	26089.89	3.24	27297.75	3.39
Mangrove	328942	40.85	327089.9	40.62	326204.1	40.51
Total	805243.5	100	805243.5	100	805243.5	100
Land cover	2001		2009		2010	
	Area	%	Area	%	Area	%
Water body	403104.9	50.06	422108.64	52.42	413492.5	51.35
Mudflat	42114.23	5.23	40503.75	5.03	43563.67	5.41
Barren land	32451.31	4.03	35269.66	4.38	32451.31	4.03
Mangrove	327573.1	40.68	307361.44	38.17	315736	39.21
Total	805243.5	100	805243.5	100	805243.5	100

\* Calculated from NDVI value (each percentage column represents percentages of total area of referenced year)

#### 3.2 Water bodies

In 1973, water body in the study area occupied about 411640.47 hectares of Sundarbans forest land representing about 51.12% (Table 3) of total land cover for the year. By 2010, the area occupied by the water body increased marginally by 0.45% with about 805243.49 hectares representing 51.35% of total land cover for that period (Table 3).

The rate of decreased within inter-study periods was 0.21%, 2.19%, 2.30% and 2.05% during the period of 1978-1989, 1989-2001, and 2009-2010, respectively; whereas, increased during 1973 to 1978, and 2001 to 2009 by 0.33% and 4.71%, respectively (Table 4). The most significant increased of water bodies observed for 2009 which was attributed by the cyclone Ayla that hit on May 2009 and the percentage occupied

by water bodies (52.42%) was the highest during 1973 to 2010 (Table 3).

### 3.3 Mudflats

The percentage occupied by mudflats to the total study was around 5.41% in 2010 that increased from 4.52% in 1973, 4.85% in 1978, 4.92% in 1989 and 5.23% in 2001 (Table 3). Moreover, the rate of

increase during the inter-study period was also higher for mudflats. The percentage change analysis showed that in 2009 mudflats decreased by 3.82% compared to 2001 (Table 4). This decrease was triggered by the cyclone Ayla that resulted inundation of mudflats and increase in water bodies (Table 4).

**Table 4.** Rate of changes in land cover classes from 1973 to 2010 (rate changes with respect to their original area in the respective year)

Land cover	1973 to 1978	1978 to 1989	1989 to 2001	2001 to 2009	2009 to 2010
Water body	0.33%	-0.21%	-2.19%	4.71%	-2.04%
Mudflat	7.30%	1.44%	6.30%	-3.82%	7.55%
Barren land	-7.69%	4.63%	18.88%	8.68%	-7.99%
Vegetation	-0.56%	-0.27%	0.42%	-6.17%	2.72%

\* Calculated from Table 3 using the equation  $\frac{Y_2 - Y_1}{Y_1} \times 100$ , where  $Y_1$  areas of previous year and  $Y_2$  areas of new year.

### 3.4. Barren lands

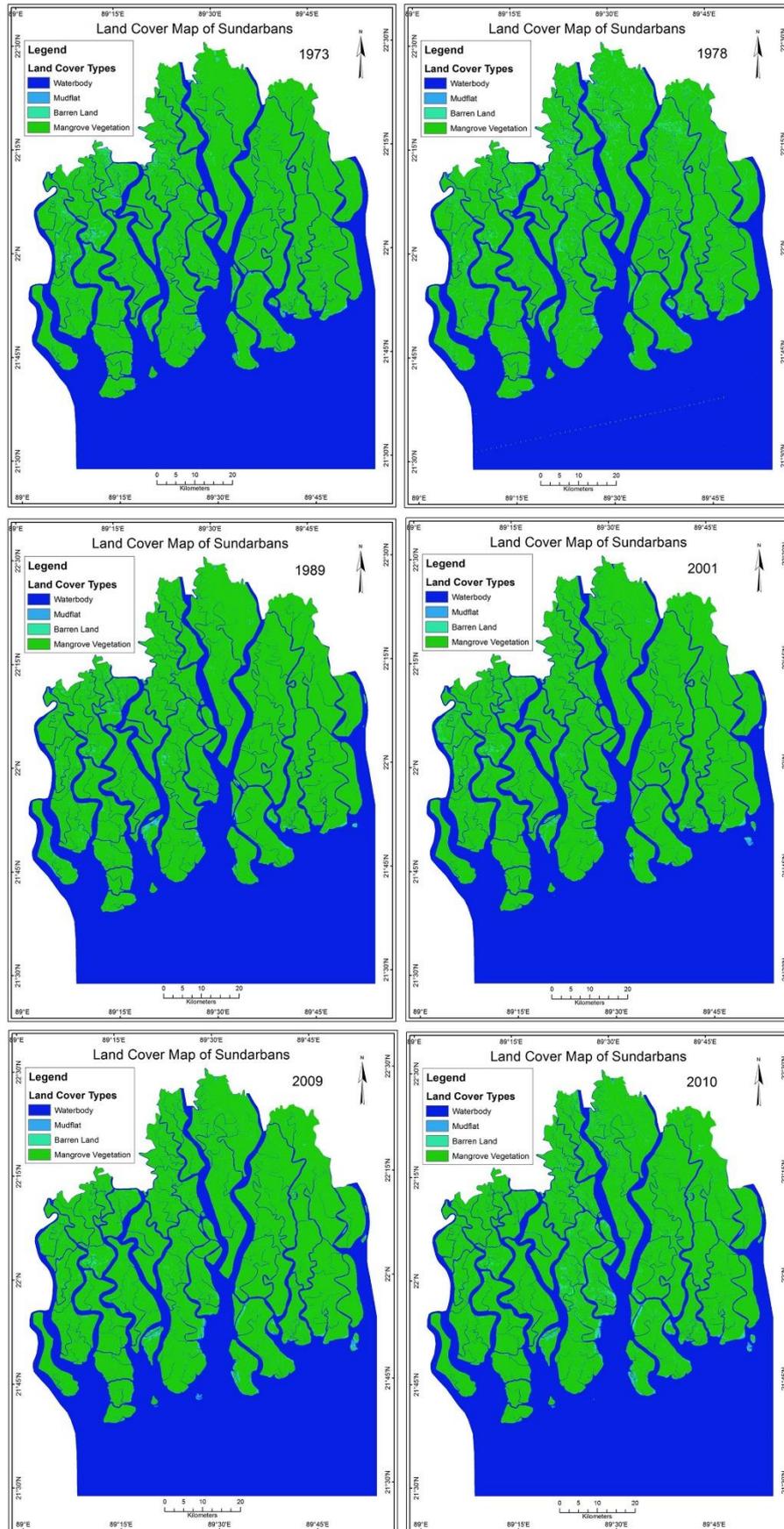
The most remarkable changed observed for barren land distribution. The amount of barren land in 1973 was 28264.05 hectares that declined significantly in 2010 to 32451.31 hectares (Table 3). In 1973, barren land occupied 3.51% to the total study area that increased and constituted 4.03%, 4.38%, and 4.03% to the total study area in 2001, 2009 and 2010, respectively (Table 3). The inter-study declined rate for barren land was also higher than other three categories (Table 4). During 1989 and 2001, total area occupied by barren land increased by 18.88% which was the highest growth rate observed among all land cover categories (Table 4).

### 3.5. Vegetated lands

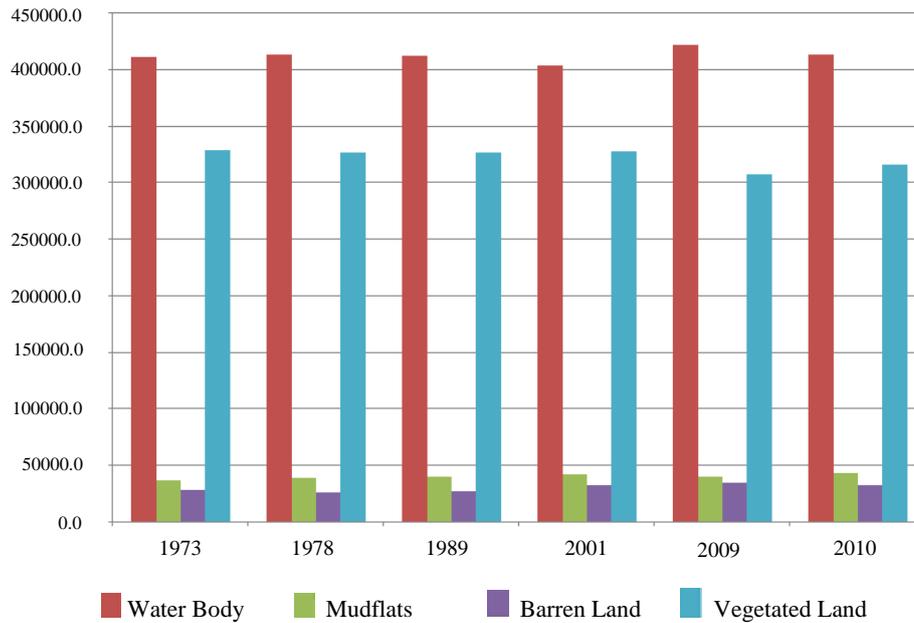
The dense vegetation forest (included both mangrove and non-mangrove species) area decreased at a steady rate throughout the study period. Vegetated area covered 328941.97 hectares in 1973 (Table 3). It was merely dropped in 1978

and covered around 327089.91 hectares. Vegetated land again dropped in 1989 and reached about 326204.14 hectares. Furthermore, vegetated land decreased in 2001 and 2009 which was 327573.05 hectares and 307361.44 hectares, respectively (Table 3). The analysis demonstrated that vegetated land constituted 40.85%, 40.62%, 40.51%, 40.68% and 38.17% in 1973, 1978, 1989, 2001 and 2009, respectively to the total study area (Table 3). The highest decline rate of vegetated land was 6.17% in 2009 when cyclone Ayla landfall (Table 4). Moreover, regional variations in vegetation coverage were also observed throughout the study years. Dense vegetation was apparently distributed uniformly in the forest except 2009 (Figure 3). In 2010 (post-cyclone Ayla), water bodies and barren lands decreased by 2.04% and 7.99% respectively, whereas, mudflats and vegetated land increased by 7.55% and 2.72%, respectively (Table 4).

The areas occupied by water bodies, mudflats, barren lands, and vegetated lands from 1973 to 2010 were presented in Figure 4.



**Figure 3.** Land cover map of Sundarbans in different years (1973, 1978, 1989, 2001, 2009 and 2010)



**Figure 4.** Graphical presentation of areas occupied by water bodies, mudflats, barren lands, and vegetated lands from 1973 to 2010 (calculated from NDVI)

According to FAO (2007), the Sundarbans reserved forest is well protected, and no major changes have been found during 1980 to 2005. The same finding was also observed in this study. The resource extraction has been aggravated by population pressure around the interface localities of SRF. Someone may conclude unsustainable and illegal harvesting of forest resources is the major contributory factor for spatial and temporal changes in the tree cover of SRF. Nevertheless, population size of Sundarbans impact zone upazila's (sub districts) decreased from 22,074,05 in 2001 to 21,558,89 in 2011 (BBS, 2001; BBS, 2011). On the other hand, population growth rate was also negative during 2001 to 2011, yet vegetated land from Sundarbans decreased during 2001 to 2009. This decreased could be explained by climate induced disasters. In the last decade (between 2001 and 2011), several cyclones had landfall through Sundarbans. Cyclone Sidr (landfall on 15 November 2007 with an average wind speed of 223 km per hour) and cyclone Aila (stuck on 25 May 2009) were the two most devastated disasters that caused serious damage to Sundarbans, trees were uprooted and broken down, thousands of animals of Sundarbans died, saline water flushed into the forest causing fresh water scarcity for biotic species. After the landfalls of those two consecutive cyclones, impact of climate change has become more

pronounced in the southern coastal zone of Bangladesh. Therefore, Sundarbans is the innocent victims of climate induced disasters in many ways. The notable impacts of climate change on Sundarbans would be sea level rise, increases in frequency and intensity of cyclonic storm, irregular rainfall, salinity ingression, and many more.

The SRF is the single largest contiguous mangrove forest ecosystem in the world. According to FAO (2007), the physical boundary of the reserve forest has changed several times over the years, and the creation of the protected area ended in 1932/1933, and the limit of the reserved forest has not changed since then. Thereafter, the Sundarbans Reserved Forest appears to have been relatively well protected and the area has been kept relatively intact (Wilkie and Fortuna, 2003). The study of Rahman and Begum (2013) found no notable change in mangrove forest during 1980 to 2009. This study also revealed that geographical boundary of SRF is well conserved by the government except changes in land cover (water bodies, mudflats, barren lands and vegetated lands) within Sundarbans reserved forest.

#### 4. CONCLUSIONS

The natural forest of Bangladesh has been declining significantly. The annual loss of forest in Bangladesh is estimated around 0.015 million hectares (Choudhury and Hossain, 2011). The area

under mangrove was 3.35% in 2000 which increased from 3.12% in 1976 (Hasan et al., 2013). This increase of mangrove forest was attributed by mangrove plantation along the shore land of coastal districts up to 2000 (Hasan et al., 2013).

To understand land cover dynamics of Sundarbans over last 37 years, four major land cover classes were categorized-water body, mudflat, barren lands and vegetated lands. The major finding of this research work is that the legal forest area (geographical boundary) of Sundarbans reserved forest in Bangladesh had not changed during study period and theoretically, it is now well conserved. But while analyzing the temporal changes in land cover classes, this study found significant fluctuation of different land cover classes. From 1973 to 2010, water bodies, mudflats and barren lands increased by 0.45%, 19.69% and 14.81%, respectively; whereas the vegetated lands decreased by 4.01% during the same period. This indicates that density of evergreen vegetation and its canopy closure has been decreasing. The increase in mudflats was attributed by erosion and deposition in the forest, while increase in barren lands was due to both anthropogenic factors (illegal falling, decrease in freshwater flow) and natural forces (climate induced severe cyclones, surges and salinity ingressions).

Hypothetically, if government develops strong policies and takes effective and efficient legal measures to conserve Sundarbans from illegal harvesting, even after Sundarbans will further be degraded because of climate change impact which was the major thrust of this research work. The recommendations of this paper to develop GIS and RS based regular monitoring system that can easily identify temporal and spatial changes of forest cover of Sundarbans. Along with that comprehensive protection measures should be taken at national and international level to conserve Sundarbans. Political commitment and willingness on trans-boundary river management is also important to protect Sundarbans from human induced climate change impacts.

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