VEGETATION CHANGES OF SUNDARBANS BASED ON LANDSAT IMAGERY ANALYSIS BETWEEN 1975 AND 2006

MD. TARIQUL ISLAM

Department of Earth Sciences, University of Gothenburg
Box 460, 405 30 Gothenburg, Sweden
E-mail, tariqul.islam@gvc.gu.se

Received 9 October 2013, accepted in revised form 23 June 2014

Abstract

The Sundarbans in Bangladesh and India is the largest single block of tidal halophytic mangrove forest in the world. This forest is threatened by effect of climate change and manmade activities. The aim of this paper is to show changes in vegetation cover of Sundarbans since 1975 using Landsat imagery. Normalized Difference Vegetation Index is applied to quantify and qualify density of vegetation on a patch of land. Estimated land area (excluded water body) of this forest is 66% in Bangladesh, and 34% in India, respectively. Net erosion since 1975 to 2006 is ~5.9%. In vicinity of human settlement, areal changes are not observed since 1975. The mangrove forest is decreased by 19.3% due severe tropical cyclone in 1977 and 1988. Moreover, the dense forest is damaged by about 50%. However, more than 25 years is taken by Sundarbans to recover from damage by a severe tropical cyclone. The biodiversity of Sundarbans depends to fresh water flow through it. Therefore, the future of Sundarbans depends to the impact of climate change which has further effect to increasing intensity and frequency of severe tropical cyclone and salinity in water channels in Sundarbans.

Keywords: mangrove forest cover change, Sundarbans, Landsat imagery, Normalized Difference Vegetation Index

1. Introduction

Normalized difference Vegetation Index (NDVI) is a significant tool to monitor vegetation coverage. It allows research on areal context as well as quality of vegetation in terms of chlorophyll response of electromagnetic spectrum (Elmore et al. 2000; Jackson et al. 2004). The aim of this study is to monitor Sundarbans since 1975 to 2006. NDVI is applied as a tool to identify areal as well as qualitative changes using Landsat imagery.

The Sundarbans is located at the delta of the Ganges, Brahmaputra and Meghna rivers systems on the Bay of Bengal in Bangladesh and India. It is declared a World Heritage in 1997 by United Nations Educational Scientific and Cultural Organization (UNESCO) (Chowdhury 2010). It is the largest single block of tidal halophytic mangrove forest which holds ~28% world's mangrove forest (Salam et al. 2000).

In many aspects, Sundarbans has great importance. It provides a big economic zone in both Bangladesh and India. There are about 0.5-0.6 million people in Bangladesh directly depend to Sundarbans. They collect honey, shells, crabs, fishes, shrimps, wood and fuel-wood for six months in a year (Haq 2010). This is also similar scenario in India (Danda et al. 2011). In 1980s, about 45% of total timbers and fuel woods in Bangladesh were taken from this forest (Rahman 2000). It supplies raw materials for many industries. It is also a unique place of mangrove eco-tourism (Salam et al. 2000). It is a forest of complex ecosystem consists of different species of about 334 plans, 120 fishes, 35 reptiles, 270 birds and 42 mammals including the famous Royal Bengal Tiger and estuarine crocodile (Rahman 2000). In fact it is also working as a safeguard from tidal surge and tropical cyclone.

However, Sundarbans is threatened by the impact of climate change and manmade activities. Sea surface air temperatures over the Bay of Bengal is rising at a rate of 0.019 °C/yr (Danda et al. 2011). By 2050, temperature will increase ~1 °C is reported by the Indian Sundarbans Delta (Danda et al. 2011). Now, the relative mean sea level is rising about 8 mm/yr that was 3.14 mm/yr in the last decade (Danda et al. 2011). It is triggering high intensity and frequency of tropical cyclonic activities and salinity in soil and water body which damage vegetation in Sundarbans. Center for Environmental and Geographic Information Services (CEGIS) (2007) reported that ~190,000 ha of this forest are severely damaged by Cyclone "Sidr" on 15 November 2007. Average vegetation growth in 2008-09 was four times less than in 2009-10 (Bhowmik – Cabral 2013). On the other hand Sundarbans dependent population is growing very fast who extract natural resources directly is also a big challenge reported by District Human Development Report (DHDR) (2009).

2. Methods

2.1. General characteristics of Sundarbans

The Sundarbans has total coverage of ~1,020,000 ha. The share of it between in Bangladesh and India is ~600,000 ha (59%) and ~420,000 ha (41%), respectively (DHDR, 2009). Share of land area in Bangladesh is ~70% (out of 59%) and remaining 30% area is under water in form of rivers, lakes, canals and so on (Rahman 2000). Whereas in India, the vegetated land area covers is ~55% and remaining 45% is under water (DHDR 2009). It is extended approximately 88.3-90.25 °E and 21.54-22.5 °N (Fig. 1). The green areas in figure 1 indicate forest area. Elevation in this forest varies 0.9-2.11 m above sea level (Rahman 2000). Tropical climate exists at Sundarbans with annual maximum temperature is 35 °C, average humidity is 82% and annual average rainfall is 192 cm whereas 75% rainfall occurs between June to September. Average tidal amplitude in the estuaries ranges from 3.5 m to 4 m. The

Fig. 1. Location of Sundarbans adapted from Choudhury, 2012

Table 1. Details of used data sets

Images	Sensor	Id	WRS	Path	Row	Acquisition date	Spatial resolution (m × m)
A	A1	MSS	1	148	045	1975-12-05	57 × 57
	A2	MSS	1	147	045	1977-01-03	57 × 57
B	B1	TM	2	137	045	1989-01-12	28.5 × 28.5
	B2	TM	2	138	045	1989-01-03	28.5 × 28.5
C	C1	ETM+	2	138	045	2000-11-17	28.5 × 28.5
	C2	ETM+	2	137	045	2000-11-26	28.5 × 28.5
D	D1	ETM+	2	138	045	2006-11-18	30 × 30
	D2	TM	2	137	045	2006-11-03	30 × 30

fluctuation of water level is usually high from August to September. During this time, the highest tide level is exceded 4 m (DHDR 2009).

2.2. Data sets

This study is conducted applying UTM projected Landsat imagery from the Global Land Cover Facility (GLCF 2004). Near Infrared (NIR) (0.7-0.8 μm for MSS and 0.76-0.90 μm for TM and ETM+) and Red (0.6-0.7 μm for MSS and 0.63-0.69 μm for TM and ETM+) bands are used. Those are cloud free and acquired from the dry season. The spatial resolution of Landsat images is large enough to monitor vegetation coverage in large scale (Priestnall – Aplin 2006). Properties of Landsat images used in this study are presented in Table 1.

2.3. Noise correction

The time series Landsat imagery are processed and quantified using ArcMap 10 software. Some images are noise free and some are noise prone e.g., Image D1. Image D1 consists of NoData (Fig. 2) which requires removing NoData region. The noised area (with NoData region) is separated as a subset using a mask. A 5 by 5 kernel filter (Burrough – McDonnell 1998; Heywood et al. 2011) is applied which fills up digital number (DN) value of NoData region by mean value. It would affect rest of DNs values of this subset.

The filtered subset is converted to point feature where each pixel creates a single point. The points of mean DNs values where there is NoData at the original subset are separated and converted to raster with similar pixel resolution. The newly formed raster from points data is merged to the

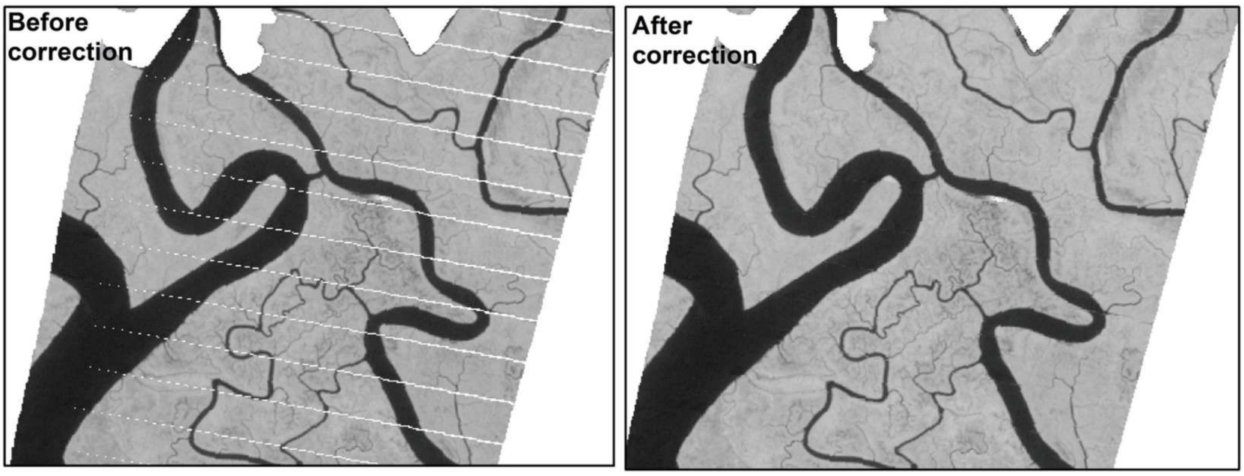

Fig. 2. A section of image D1

Table 2. Correlation coefficient of regression analysis

Equations	Correlation coefficient (R2)	Used images
y = 0.74x + 10.44	0.77	y = A1, MSS band 2; x = A2, MSS band 2
y = 0.66x + 11.99	0.91	y = A1, MSS band 3; x = A2, MSS band 3
y = 2.30x + 12	0.70	y = C, ETM+ band 3; x = A, MSS band 2
y = 1.87x + 26.35	0.73	y = C, ETM+ band 4; x = A, MSS band 3
y = 1.18x + 20.39	0.82	y = C, ETM+ band 3; x = B, TM band 3
y = 1.60x + 8.82	0.90	y = C, ETM+ band 4; x = B, TM band 4
y = 1.04x + 20.94	0.78	y = C, ETM+ band 3; x = D, ETM+ band 3
y = 1.04x + 15.14	0.93	y = C, ETM+ band 4; x = D, ETM+ band 4

original subset. In the corrected subset, DNs values of NoData are replaced by mean values of kernel filter. It preserves all original DNs values except DNs values of NoData. Then the corrected subset is combined with rest of data set of Image D1. The figure 2 shows a section of noise prone of Image D1 and after its correction. Then, spatial resolution of all images is resampled to common size 28.5 m X 28.5 m using nearest neighbor resampling method which reserves original DN's value (Campbell 2002).

2.3. Radiometric correction

The area of Sundarbans is not covered by these images separately. Therefore Image A1 and A2, B1 and B2, C1 and C2, and D1 and D2 are needed to merge together. However, those pairs of images were not acquired in same time. It influences the variation of reflectance due to satellite sensor calibration, change in illumination and observation angels, atmospheric effects and difference in target reflectance over time which has further effect on NDVI (e.g., Du et al. 2002; Govaerts – Verhulst 2010). Therefore relative radiometric normalization is performed by applying first order linear regression method (e.g., Du et al. 2002; Mateos et al. 2010). Temporal variation of image acquisition of Image A1 and A2 was ~13 months. Therefore Image A2 was radiometrically normalized reference to Image A1. There were no recorded severe tropical cyclone and tidal surge occurred during December 05, 1975 to January 03, 1977. After normalization, Image A2 is assumed to represent the land covers in 1975 as in Image A1. Those images (Images A1 and normalized A2) are merged together and formed Image A. Temporal variations of acquisition of rest of the images were 9 (B1 and B2, C1 and C2) and 15 (D1 and D2) days. Reflectance level (DN value) was checked and those pair images give fairly similar the DNs values of same land covers. Therefore Image B1 and B2, C1 and C2, and D1 and D2 are merged together and formed Images B, C and D, respectively. NDVI of these images (Images B, C and D) may have minor noise. Moreover, those are assumed not to have further effect on identification of land covers since identified land covers in this study is in level I that can be classified without ancillary data (Thompson 1996). Then Images A (in 1975), B (in 1989) and D (in 2006) is radiometrically normalized relative to reference Image C (in 2000). Clean water (lake's and pond's water), roads, dry sands and bare soil (fallow land) are selected as pseudo invariant features (PIF) for linear regression analysis which is often referred to as radiometric ground control points (Jensen 2005). Correlation coefficients and equations of regression analysis for radiometric normalization are presented in Table 2.

2.4. Normalized Difference Vegetation Index (NDVI)

NDVI is calculated as (Elmore et al. 2000; Jackson et al. 2004)

Table 3. Classified areas according to NDVI values in different years (B and I is referred to Bangladesh and India).

Value		In 1975		In 1989		In 2000		In 2006	
RCL	NDVI	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Barren land	0-0.2	60380.1 (B47.2%; I52.8%)	8.9	180944.6 (B36.5%; I63.5%)	28.2	14238.9 (B49.1%; I50.9%)	2.3	38502.36 (B61.3%; I38.7%)	6
Grass land	0.2-0.3	127884.1 (B49.2%; I50.8%)	18.9	350791.4 (B72.7%; I27.3%)	54.7	21036.7 (B41.6%; I58.4%)	3.5	206142.2 (B87.6%; I12.4%)	32.4
Vegetated land	0.3-0.4	465569.3 (B71.4%; I28.6%)	68.8	109912.8 (B95%; I5%)	17.1	78011.2 (B57.4%; I42.6%)	12.7	356424 (B58.5%; I41.5%)	56
	0.4-0.5	22414.2 (B90%; I10%)	3.3	50.1 (B100%; I0%)	0	499485.5 (B70.3%; I29.7%)	81.5	35431.5 (B20%; I80%)	5.6
	Total	487983.5 (B72.2%; I27.8%)	72.2	109962.9 (B95.1%; I4.9%)	17.1	577496.7 (B68.5%; I21.5%)	94.2	391855.5 (B55%; I45%)	61.6
Total		676247.7 (B65.6%; I34.4%)	100	641698.9 (B66.3%; I33.7%)	100	612772.3 (B67.2%; I32.8)	100	636500 (B66%; I34%	100

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

where, R_{NIR} is reflected and/or radiated DN value of near infrared band that is in MSS's channel three, and in TM's and ETM+'s channel four.

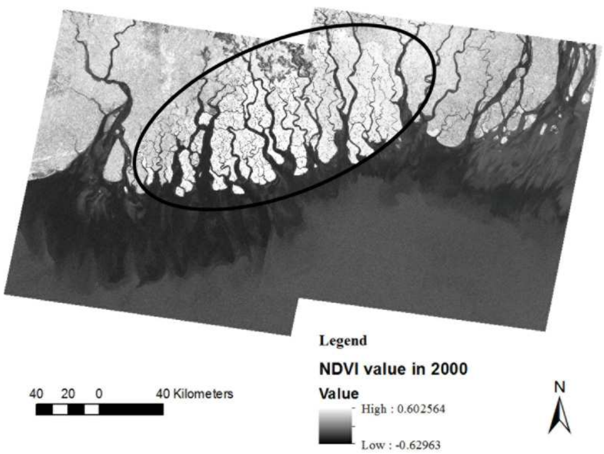

Fig. 3. NDVI values in 2000

The R_{RED} is visible red band that is in MSS's channel two, and in TM's and ETM+'s channel three. Then the area of Sundarbans in 1975 is separated using a mask which is considered as initial area of this forest for this study. This mask is created based on visual interpretation since the Sundarbans can be clearly demarked by rivers, cannel and other form of water body which provides high variation in NDVI raster layer (Fig. 3). The bright areas marked by ellipse in Fig. 3 are Sundarbans. Further, the NDVI raster layer is classified as 0.001-0.1 to barren land, 0.2-0.3 to grass land and 0.3-1.0 to vegetated land (Fig. 4 and Table 3). The NDVI less and equal to 0 is kept out as water body. This classification is conducted based on studied by Weier and Herring (2013). Furthermore, the vegetated area is classified into two classes with assigned NDVI's DN values as range in Table 3.

3. Results and discussions

Total land area (excluded water body) in Sundarbans is obtained ~ 676248 ha for 1975 where share of Bangladesh and India is ~66% and ~34% (Table 3). The area is fairly similar with mentioned by others (e.g., Rahman 2000; Giri et al. 2007; Haq 2010; Danda et al. 2011; Bhowmik – Cabral 2013). The estimated land area in 1989 and 2000 is ~641699 ha and ~612772 ha what is 4.9% and 7.7% less than founded by Giri et al. (2007).

During 1975-89 and 1989-2000, the land area was decreased by ~5.1% and ~4.5%, respectively. Then during and 2000-06, it was increased ~3.9%. Decreasing and increasing of land area is caused of erosion and deposition what was found by Shibly – Takewaka (2013) who studied near shoreline in Sundarbans. However share of vegetated area by Bangladesh and India is more or less constant during observation period since 1975 to 2006. Net decrease of land area since 1975 to 2006 is ~5.9%. It indicates that bank of water channel and shore of Bay of Bengal exhibit more erosion than deposition which has good agreement with others (Gopal – Chauhan 2006; Raha et al. 2012).

Variation of NDVI value in different parts of Sundarbans is observed over time. However, during the observation period 1975-2006, NDVI, greater than 0.4 is dominated by part of Sundarbans in Bangladesh (Fig. 4 and Table 3). It indicates that healthy vegetated land cover is proportionally higher in Bangladesh than India. However, the pic NDVI, 0.7-1 is almost absent during observation period. Analysis of variation of NDVI in Sundarbans shows that NDVI decreases during 1975-1989 severely and also during 2000-2006 but not significantly. It increases during 1989-2000 (Fig. 4 and Table 3). Shibly –

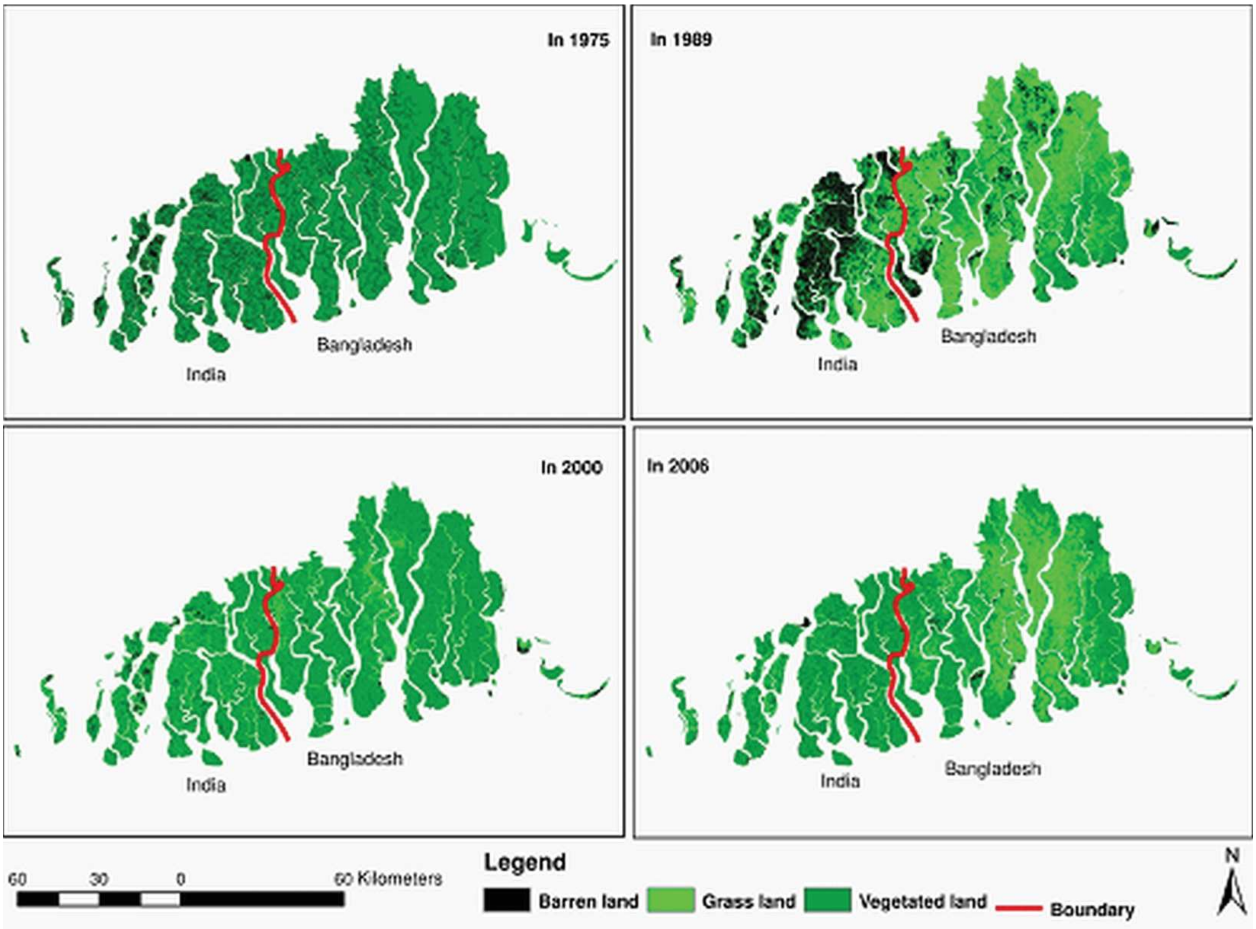

Fig. 4. Land covers in Sundarbans except water channels

Takewaka (2013) suggested NDVI decreases during 1995-2000 and increases 2000-2005. However, it can't be compared with this study, since observation time scale was different and they studied some selected locations and profiles near shoreline in the part in Bangladesh.

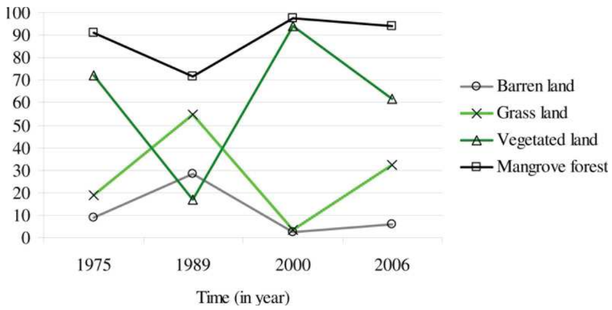

Fig. 5. Percent of land covers in different years. The y axis is presented in percent. The mangrove forest is estimated by combining grass land and vegetated land

The vegetation density can be qualified by growth of vegetation that is directly linked with NDVI value (Bhowmik – Cabral 2013). In this study, vegetated and grass land are referred to mangrove forest. However, the vegetated area is loosely referred to dense forest area. Mangrove forest area is significantly low (Fig. 5) and the barren land, the lower NDVI value (0-0.2) is high in 1989 (Table 3). It is caused of severe tropical cyclones in 9-12 May, 1977 and 24-30 November, 1988. Therefore, the mangrove forest area was decrease by ~19.3% what is fairly similar with damaged by a severe tropical cyclone named "Sidr" (22%) in 15 November 2007 (Bhowmik – Cabral 2013). The dense forest area is decreased by 50% (Fig. 5 and Table 3). The post tropical cyclone lower vegetation growth is observed during 1975-1989. Then vegetation growth accelerates until 2000. The mangrove forest and barren land area is more or less constant during 2000-2006 (Figs. 4 and 5, and Table 3). There is no significant difference of vegetation growth observed in 1975, 2000-2006 (Fig. 5 and Table 3). Loosely, it can be said that the recovery time for Sundarbans from deforestation by a severe tropical cyclone may be about 25 years.

During 1975-2006, there is no significant change of mangrove forest area observed in this study except in 1989 (Fig. 5). Giri et al. (2007) also did not find any significant changes in mangrove forest in Sundarbans during 1977-2000. However, they did not address the effect of severe tropical cyclones in 1977 and 1988 on Sundarbans. But a severe tropical cyclone may damage ~20% of the forest area (in this study and, Bhowmik – Cabral 2013).

In 2006, the central part of Sundarbans in Bangadesh experiences less vegetated land but high grass land (Figs. 4 and 5). This may be during and post effect of high salinity. Since high level of salinity is observed since late 1980s (Shibly – Takewaka 2013). Sundari trees (*Heritiera fomes*) in Sundarbans are affected since 1950 because of salinity. It is accelerated after Farakka barrage construction in 1975 in India. The frequency of these tree species decreased to the half because of the increasing water salinity from 10 to 20 g kg^{-1} (Kamol 2011). Kamol (2011) also mentions that the situation for other types of trees is similar. Upstream fresh water flow is being decreased which is controlled using Farakka barrage. To protect biodiversity in Sundarbans, minimum water flow through Gorai River is required to 100 $m^3 s^{-1}$. But actually only 30 $m^3 s^{-1}$ water flow could be observed in this channel (Kamol 2011).

Due to global climate change, average temperature and spatio-temporal variability in precipitation is increased which enhance frequency of severe tropical cyclones (Ellison 1994; Danda et al. 2011). The frequency of severe tropical cyclones is increased by 26% over Bay of Bengal those threats to Sundarbans (Danda et al. 2011). Sea level rising, tropical cyclones and storm surges which further change interaction between fresh and saline water that effects on mangrove forest (Gopal – Chauhan 2006). Manmade activities like increasing Sundarbans dependency population who extract natural resources and mainly Farakka barrage by which upstream fresh water controlling threats to the sustainability of

Sundarbans (Gopal – Chauhan 2006; Kamol 2011; Shibly – Takewaka, 2013).

4. Conclusions

Human activities based on Sundarbans affect to this forest's biodiversity. However, deforestation and thus areal decrease at the edge of Sundarbans and in vicinity of human settlement is not observed during this observation period 1975-2006. In this period, net erosion is observed to 5.9%. The forest is severely damaged by tropical cyclone. Recovery time from damaged by a tropical cyclone may take ~25 years. Biodiversity of Sundarbans depends to flow of upstream fresh water. Moreover, many industries and factories, those were dependent to Sundarbans were closed down early 2000s in Bangladesh. Awareness building, monitoring and controlling activities in both Bangladesh and India are increased and facilitated by government of Bangladesh and India, the International Union for Conservation of Nature, World Bank, UNESCO and so forth.

Therefore, the future of Sundarbans depends to climatic issues e.g., salinity, frequency of severe tropical cyclone and tidal effect those directly depend to global warming. Not local manmade activities but Farakka barrage triggers to control fresh water flow in the Sundarbans and threats to preserve the biodiversity in the Sundarbans.

Acknowledgements

This study was depended to Landsat Imagery. Author would like to thank to Global Land Cover Facilities for available cost free Landsat Imagery. The anonymous reviewers are gratefully acknowledged.

5. References

Bhowmik, A. K. – Cabral, P. (2013): Cyclone Sidr Impacts on the Sundarbans Floristic Diversity. Earth Science Research 2 (2): 62-79.

Burrough, P. A. – McDonnell, R. A. (1998): Principles of Geographical Information System. Oxford University Press Inc., New York, USA.

Campbell, J. B. (2002): Introduction to Remote Sensing. 3rd ed., New York, USA.

CEGIS, (2007): Effect of cyclone Sidr on the Sundarbans, A Preliminary Assessment.

Choudhury, A. (2012): Sundarban: Suffusion theme by Sayontan Sinha. http://www.210countries.com/destinations/off-the-beaten-path/sundarban/ (downloaded in 2013)

Chowdhury, M. T. A. (2010): Resource-dependent livelihoods in the Sundarbans. CRMOM Small Publications, 18, Solo, Central Java, Indonesia.

Danda, A. A. - Sriskanthan, G. - Ghosh, A. - Bandyopadhyay, J. - Hazra, S. (2011): Indian Sundarbans Delta: A Vision. New Delhi, World Wide Fund for Nature-India.

DHDR (2009): South 24 Parganas. Development and Planning Department, Government of West Bengal, India.

Du, Y. – Teillet, P.M. – Cihlar J. (2002): Radiometric normalization of multitemporal high-resolution satellite images with quality control for land cover change detection. Remote Sensing of Environment 82: 123-134.

Elmore, A. J. – Mustard, J. F. – Manning, S. J. – Lobell, D. B. (2000): Quantifying Vegetation Change in Semiarid Environments: Precision and Accuracy of Spectral Mixture Analysis and the Normalized Difference Vegetation Index. Remote Sensing of Environment 73: 87-102.

Giri, C. – Pengra, B. – Zhu, Z. – Singh, A. – Tieszen, L. L. (2007): Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1993 to 2000. Estuarine, Coastal and Shelf Science 73: 91-100.

GLCF (2004): Earth Science Data Interface. University of Maryland, USA. http://glcfapp.glcf.umd.edu:8080/esdi/ (downloaded in 2013)

Gopal, B. – Chauhan, M. (2006): Biodiversity and its conservation in the Sundarban Mangrove Ecosystem. Aquatic Sciences 68: 338-354.

Govaerts, B. – Verhulst, N. (2010): The normalized difference vegetation index (NDVI) GreenSeekerTM handheld sensor: Toward the integrated evaluation of crop management. Part A: Concepts and case studies. Mexico, D.F, CIMMYT.

Haq, S. A. (2010): Impact of climate change on "Sundarbans", the largest mangrove forest: ways forward. 18th Commonwealth Forestry Conference, 28 June - 2 July, Edinburgh, UK.

Heywood, I. – Cornelius, S. – Carver, S. (2011): An Introduction of Geographical Information

Systems". 4th ed., Pearson Education Ltd., Harlow, England.

Jackson, T. J. – Chen, D. – Cosh, M. – Li, F. – Anderson, M. – Walthall, C. – Doriaswamy, P. – Hunt, E. R. (2004): Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans. Remote Sensing of Environment 92: 474-482.

Jensen, R. J. (2005): Introductory Digital Image Processing: A Remote Sensing Perspective. 3rd ed., Prentice-Hall, Inc., New York, USA.

Kamol, A. E. (2011): Rising salinity threatens Sundarban. New Age, Online Ed., http://newagebd.com/newspaper1/archive_details.php?date=2011-09-05&nid =32210 (downloaded in 2013)

Mateos, C. J. B. – Ruiz, C. P. – Crespo, R. G. – Sanz, A. C. (2010): Relative Radiometric Normalization of Multitemporal images. A Direct path to Intelligent Tools 1(3): 54-59.

Priestnall, G. – Aplin, P. (2006): Spatial and temporal remote sensing requirements for river monitoring. International Journal of Remote Sensing 27(11): 2111-2120.

Raha, A. – Das, S. – Bajerjee, K. – Mitra, A. (2012): Climate change on Indian Sundarbans: a time series analysis (1924-2008). Biodivers Conserv 21: 1289-1307.

Rahman, L. M. (2000): The Sundarbans: A Unique Wilderness of the World. USDA Forest Service Proceedings, RMRS-15(2): 143-148.

Salam, M. A. – Lindsay, G. R. – Beveridge, M. C. M. (2000): Eco-tourism to Protect the Reserve Mangrove Forest the Sundarbans and its Flora and Fauna. Anatolia: An International Journal of Tourism and Hospitality Research 11(1): 56-66.

Shibly, A. M. – Takewaka, S. (2013): Morphological changes and vegetation index variation along the western coastal zone of Bangladesh. Proceeding of the 7th International Conference on Asian and Pacific Coasts: 153-158

Thompson, M. (1996): A Standard Land-cover Classification Scheme for Remote Sensing Application in South Africa. South African Journal of Science 92.

Weier, J. – Herring, D. (2013): Measuring Vegetation (NDVI & EVI). Earth Observatory. http://earthobservatory.nasa.gov/Features/MeasuringVegetation /measuring_vegetation_1.php (downloaded in 2013)