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Abstract

Bangladesh is a riverine country with several estuarial islands, these islands are subjected to dynamic erosion and accretion. Increased sea level could consume about 26% of land in low lying zone like Bangladesh by 2100. In this alarming situation, monitoring coastline dynamics is obligatory to assess the current status of coastline so that essential measures can be taken to compensate the damage. In this study remote sensing and geographical information system (GIS) techniques have been used to quantify the erosion and accretion of land along the coastline of Moheshkhali Island, Bangladesh. Satellite images form Thematic Mapper (TM) has been used from 1996 to 2016. Modified Normalized Water Index (MNDWI) algorithm has been applied to separate land from water and on screen digitization has been adopted to extract coastline form images of 1996, 2006 and 2016 respectively. Finally, overlaying the digitized maps, the erosion and accretion has been quantified. The result shows that the western and the south-eastern part of the island faced total accretion of 4830 hectares. Erosion on the other hand was not so dominant in the study area during the 20 year time span. The finding contradicts previous works done for estuarine islands as estuarine island face both erosion and accretion. The root of this anomaly is engraved in a tidal swamp forest named "mangrove".

Keywords— Integrated Technique, Landsat, MNDWI, Accretion, Erosion, On-screen digitization

Introduction

Coastline is where hydrosphere and lithosphere contact each other(Gens 2010). Natural disasters like cyclones and enhanced human activities are changing coastlines worldwide.(Cowart, Walsh et al. 2010),(Hapke 2011),(Ramsay 1996),(Zhang, Douglas et al. 2004),(Morhange, Goiran et al. 2000) At many regions the rate of erosion is alarming and has been considered a serious hazard (Addo, Walkden et al. 2008). Along with the globe, coastline of Bangladesh is subjected to dynamic accretion and erosion (Sarwar and Woodroffe 2013).Being a deltaic and low-lying zone accumulated by the sediments of the Ganges and Brahmaputra rivers the geology is seriously threatened by global sea level rise, tropical cyclones, and temperature variations. The change of land through erosion and accretion plays an important role in shifting people from that zone and changing their occupation. The land use pattern changes the people's way of living. For example the catastrophic cyclone of April 1991 (Khalil 1993). So regional coastline dynamics is needed to design viable land use and protection strategies and reliable techniques are needed to monitor coastlines and their behavior over time.

Sea level rise caused by global warming and coast line change results in both social and economic loss (Leatherman 2001). Islands that are situated in estuary faces both gain and loss of land resulting and are subjected to hazards like saline water intrusion, tropical cyclones (Werner and Simmons 2009). Low-lying deltas like Bangladesh could face a sea level 3.3 to 4.5 meters higher than at present by the year 2100 resulting in 26% loss of the country. This means loss of shoreline by erosion loss of mangrove forests, decreased agricultural land and fisheries; overall a catastrophe.

Remote sensing and geographical information system (GIS) have been widely used to assess these changes (Ryu, Won et al. 2002),(Yamano, Shimazaki et al. 2006) along coastline. Remote sensing is a low-cost and less time- consuming approach for this type of analysis. Many advanced techniques have been adopted worldwide using digital image for change detection (Singh 1989)

Using different methods (Allison 1998),(Li and Damen 2010),(Mars and Houseknecht 2007),(Sarwar and Woodroffe 2013),(White and Wang 2003) extensive studies have been conducted on this field. Using Digital elevation model (DEM) data, derived from light detection and ranging (LIDAR), an approximately 70-km stretch of the southern North Carolina coastline was studied by Stephen A White, Yong Wang between 1997 and 2000. A new quantitative coastal land gained-and-lost method was used by J.C. Mars and D.W. Houseknecht for image analysis of topographic maps and Landsat thematic mapper short-wave infrared data to document accelerated coastal land loss and thermokarst lake expansion and drainage. The data span 1955-2005 along the Beaufort Sea coast north of Teshekpuk Lake in the National Petroleum Reserve in Alaska. Some areas have undergone as much as 0.9 km of coastal erosion in the past 50 year. Sedimentation and land reclamation was responsible for the growth of Pearl River delta, china. Xuejie Lia, Michiel C.J. Damenb have conducted an extensive study from 1960 to 2000 and they have found growth of the Island which also decreased slightly in the years after. Various large changes occurred also in the Eastern bay, along the coast of Shekou peninsula, caused by extensive harbor construction. One of the most important impacts of the coastline changes in the Pearl River Estuary is the narrowing down and extension of river channel which results in more floods in upstream.

Aerial photos and ground survey techniques had been used before GIS had opened a new and less time consuming and relatively accurate approach. Recent studies show that GIS based works are reliable and cost effective. Among different techniques like band ratio, band differencing, principal component analysis, post classification and on-screen digitization, on-screen digitization have been used in various spatial change mapping (Belal and Moghanm 2011),(DARVISHZADEH 2000).

To qualitatively deduce landform water a model is needed to enhance contrast between them. Water indices are mathematical models which enhances water signal for a given pixel on images obtained from visible/near-infrared portion of electromagnetic spectrum. Two bands, one from visible and other from infrared zone are selected to model these indices(El-Asmar and Hereher 2011).

Raw images obtained from Landsat satellite contains effect of solar radiance, reflectance, haze, dust, smoke which eventually will lead to error in results. To resolve these some corrections is needed to be done before attempting classification. There are a number of corrections like focal analysis, atmospheric correction, radiometric correction etc.
Due to solar radiance and scattering of sunlight the actual ground reflectance value gets changed. To extract the absolute surface reflectance value radiometric and atmospheric corrections are conducted (Chavez 1996),(Pons and Solé-Sugrañes 1994),(Schroeder, Cohen et al. 2006)

Methodology

Study area

The study has been conducted in Moheshkhali Islands of Cox’s-Bazar district of Bangladesh. It is an Upazila under Cox’s Bazar district. It is located in the south eastern part of the country which lies between 21°30’0”N to 21°15’0”N latitude and 91°50’0”E to 92°5’0”E longitude and has an area of 362.18 square kilometer. The island includes the Matarbari and Shonadia Island. It is separated from Cox’s Bazar District by Moheshkhali Channel. Baddar Khal and Kuhelia River have separated Matarbari and Shonadia from it. The Island is bounded by Chakaria upazila on the north, Cox's bazar sadar upazila and the Bay of Bengal on the south, Chakaria and Cox's Bazar sadar upazila on the east, Kutubdia upazila and the Bay of Bengal on the west. The economy of this locality is based on salt cultivation and shrimp culture. The geography is elevated at the center of the island and along the eastern coastline the coast to the west and north is a low-lying treat, fringed by mangrove jungle. It is not located at an estuary of any major river but has a direct interconnection with The Bay of Bengal. Being exposed to the sea at east and south, this Island is more susceptible to damage to Cyclones which results in change in landscape and shift of coastline. So, this Island has been chosen to observe the change in coastline from 1996 to 2016.

Figure 1: Maheshkhali Upazila

Data

In this study satellite images for three time steps has been used to quantify the changes along Moheshkhali Island. Satellite image of year 1996 has been extracted from Landsat 5 Thematic Mapper (TM). Image for 2006 and 2016 has been extracted from Enhanced Thematic Mapper (ETM) of Landsat 7. All the images were taken in dry season (month February) to ensure minimum cloud coverage and low water level. Both the TM and ETM has seven spectral bands that cover the visible, near infrared, short-wave infrared and thermal infrared regions of the electromagnetic spectrum: blue (0.45–0.52 μm), green (0.52–0.60 μm), red (0.63–0.69 μm), NIR (0.76–0.90 μm), mid-infrared, MIR (1.55–1.75 μm), thermal infrared, TIR (10.4–12.5 μm) and MIR (2.08–2.35 μm) (*Data source: landsat.usgs.gov*)

Other relevant GIS maps such as upazila map of study area were used as auxiliary data. Details are listed in the table below.

Table 1: List of data that has been used

Serial	Type of data	Year	Source
1	Landsat 5 TM	1996	Glovis
2	Landsat 7 ETM	2006	Glovis
3	Landsat 7 ETM	2016	Glovis
4	Moheshkhali Upazila Map	1999	LGED map 1999

Change Detection

In order to detect the change in coastline and calculate the eroded and accreted areas two different approaches were applied: (1) land and water interference discrimination for coastline identification using a water index algorithm and (2) coastline digitalization for mapping erosion/accretion patterns along Moheshkhali Island. The MNDWI water index algorithm was generated using model maker of ERDAS Imagine 2014 by using green and mid-infrared bands. A model was developed in the software to calculate MNDWI (modified normalized water index).

$$MNDWI = \frac{Green - MIR}{Green + MIR}$$

MNDWI is an algorithm with a combination of Green and Mid-infrared bands and is ideal for separating land from water. The green band (0.52–0.6 μm) is sensitive to water turbidity differences as well as sediment and pollution plumes because it covers the green reflectance peak from leaf surfaces. So it can be useful for discriminating broad classes of vegetation. The mid-infrared band (1.60–1.70 μm) on the other hand exhibits a strong contrast between land and water features due to the high degree of absorption by water and the strong reflectance by vegetation and natural features in the range. Thus, the MNDWI algorithm, which is a combination of green and mid-infrared bands, is ideal for discriminating between land and water at their interface.

The MNDWI algorithms was applied over images of 1996, 2006 and 2016 images. Then all three images were classified in ERDAS Imagine using supervised classification tool. Area of interest (AOI) had been defined before that to separate the study area and create to class, land and water.

To identify the deviation along coastline, classified images had been overlaid on one another and on-screen digitization was conducted to create the coastline layers using Arc-GIS. After that those layers were overlain together so that coastline change could be detected at each date. Coastline position were then highlighted to infer the erosion/accretion zones. In this study the coastlines were not corrected for variations in tide levels, and it was assumed that these variations were low compared to the scale of coastline shifts.

Method used for validating the result

To examine the accuracy of classified images kappa coefficient was used. Error matrices were developed taking 30 pixels for each class and the thematic accuracy was determined. The kappa coefficient (Cohen 1960) for classified image of 1996, 2006 and 2016 are 0.93, 0.96 and 0.97 with overall accuracy of 96%, 98% and 95% respectively. It suggests that MNDWI is robust technique for classifying Landsat Images with great precision.

$$\kappa = \frac{p_0 - p_e}{1 - p_e}$$

Where p_0= relative observed agreement among raters.
p_e= hypothetical probability of chance agreement.

Result and Discussion

The Modified normalized water index (MNDWI) for 1996, 2006 and 2016 are shown in figure 2 to 4. From the classified images it is observed that large amount of accretion has taken place during the 20 year study period. One the other hand very little erosion has been identified.

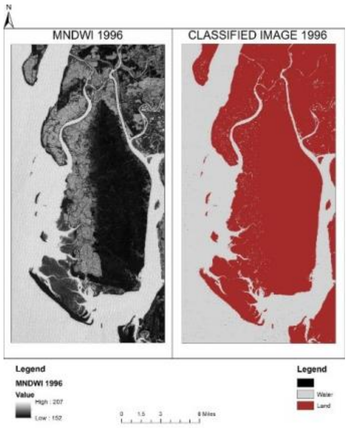

Figure 2: MNDWI & Classified Image 1996

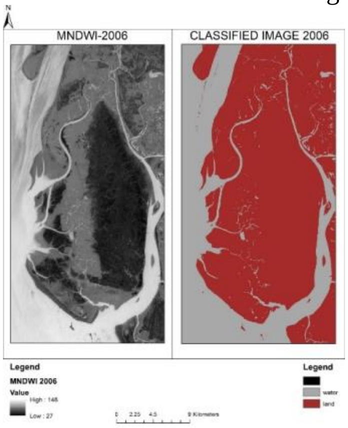

Figure 3: MNDWI & Classified Image 2006

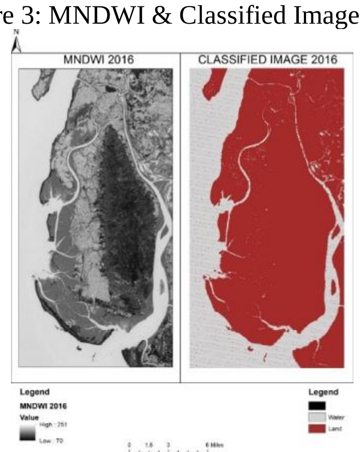

Figure 4: MNDWI & Classified Image 2016

Calculated areas of Moheshkhali Island is tabulated below. Form the table it is observed that large amount accretion, about 6236 hectares has been taken place from 1996 to 2006 and very little accretion has been taken place from 2006 to 2016. The locations where coastline change is significant are categorized as A, B, C, D, E, and F are shown in following figures. All zones except zone B are accretion dominated. Zone B shows some erosion in 20 years study period. The extent of erosion and accretion is given in Tables 2 to table 4. The change of coastline and area between 1996 and 2006 is shown in fig 5

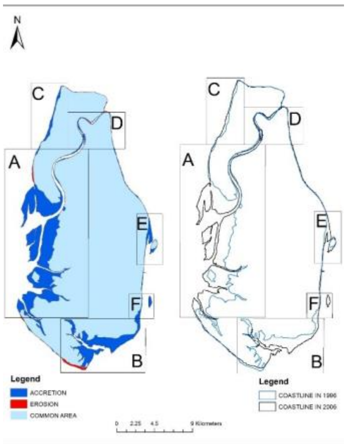

Figure 5: Maheshkhali Coastline Change (1996-2006)

Change of coastline and area between 2006 and 2016 is shown in fig 6. The result is quite astounding as the trend of accretion stops and bit and erosion takes place. Zone A faces the maximum erosion of 544.86 hectare in contrast with only 294.82 hectares of accretion. Zone A and C are erosion dominated and all the others are accretion dominated though the amount of accretion is not huge. The seaward advancement of coastline got slowed down in almost all zones and in zone A the coastline (blue line for 2016) reversed its motion towards the land.

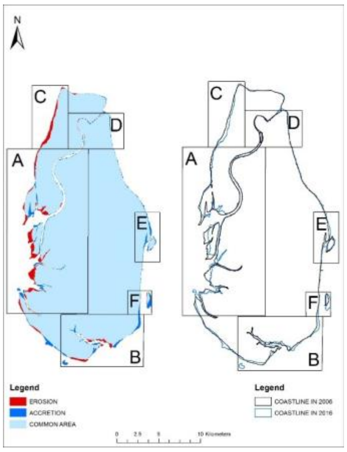

Figure 6: Maheshkhali Coastline Change (2006-2016)

Figure 7 shows the overall change during the 20 year study period from 1996 to 2016. From this image we observed that the overall change is mainly accretion. All the zones got bigger and advanced towards sea. The amount of accretion is large in zone A and B. Others are moderately accreted ranging from 94 to 162 hectare. However the total accretion is 5452.59 hectare and total erosion is 139.21 hectare resulting in neat increased area of 5313.38 hectare.

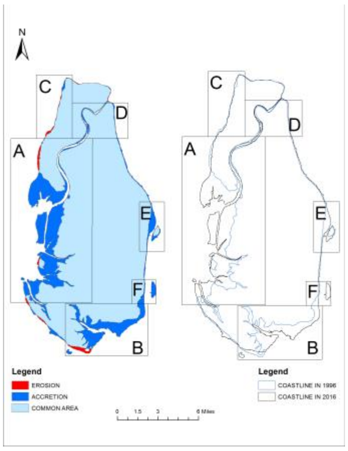

Figure 7: Maheshkhali Coastline Change (1996-2016)

Erosion and accretion of first 10 years of study period is given in table 2 and the next 10 years in table 3

Table 2: Erosion and Accretion of selected sites (1996-2006)

Zone	Erosion (hectares)	Accretion (hectares)	Overall Change	Dominant Process
A	38.63	3731.22	(+)3692.59	Accretion
B	75.96	1213.83	(+)1137.87	Accretion
C	1.13	151.94	(+)150.81	Accretion
D	20.73	98.50	(+)77.77	Accretion
E	2.76	162.81	(+)160.04	Accretion
F	0.00	94.31	(+)94.31	Accretion

Table 3: Erosion and Accretion of selected sites (2006-2016)

Zone	Erosion (hectares)	Accretion (hectares)	Overall Change	Dominant Process
A	544.87	294.83	(-)250.04	Erosion
B	117.41	197.76	(+)80.35	Accretion
C	166.75	0.47	(-)166.28	Erosion
D	15.09	38.43	(+)23.34	Accretion
E	4.86	93.77	(+)88.91	Accretion
F	7.56	80.99	(+)73.43	Accretion

The overall change of the study Island has been tabulated in table 4. From this table it is observed that during this 20 year period all the zones was dominated by accretion though some erosion took place during the second 10 years of our study span.

Table 4: Erosion and Accretion of selected sites (1996-2016)

Zone	Erosion (hectares)	Accretion (hectares)	Overall Change	Dominant Process
A	583.50	4026.05	(+)3442.55	Accretion
B	193.37	1411.59	(+)1218.55	Accretion
C	167.88	152.41	(-)15.47	Erosion
D	35.81	136.93	(+)101.11	Accretion
E	7.62	256.57	(+)248.95	Accretion
F	7.56	175.30	(+)167.74	Accretion

Moheshkhali Island has a complex and unique geological system on the eastern coast of Bangladesh. It is not an estuarine mouth but has direct contact with the sea. As a result, erosion is not the dominant force here. Therefore, the change of morphology is based on accretion, and remote sensing data also confirms this trend
Analysis of coastline change of Moheshkhali Island shows that the coastlines have changed remarkably from 1996 to 2006(fig-5) but has not shown much variation from 2006 to 2016(fig-6). During the first 10 years, accretion has been observed as the driving force in changing the coastline. The accreted land is consisted mostly of tidal deposit.(Majlis, Islam et al. 2013)

During the 20 year study period Dhalghata union became significantly large where other unions did not went through significant erosion or accretion. The astounding part of this study is that the coastline did not face any large change during 2006 to 2016. The western part of the Island is mainly tidal deposit which contains a lot of salt. Due to saline water intrusion and scarcity of sweet water the population of this region has adopted shrimp culture and salt cultivation after the cyclone of 1961 and 1963.To cultivate these they have been using the newly formed salty lands. Another thing is that the amount of mangrove forest along the eastern and western coast of this island has been increased a lot from 1996 to 2000 due to both natural and artificial plantation as this region is prone to cyclones and storm surges.

Though MNDWI is a good method for analyzing remotely sensed images, older datasets like 1996 and 2000 have resulted in lower accuracies. The kappa coefficient is also low. Nevertheless U.S. Geological survey has recommended that minimum 85% accuracy is acceptable of land/water classification (Anderson 1976).

Conclusion

Based on the study on Moheshkhali Island it can be concluded that Shoreline erosion is a continuous process with a lot of diversity, it differs from ordinary river-bank erosion as most of the islands are situated in estuary or exposed entirely to open sea. Tidal planes carry sediment which enhance the zonal area. The rate of change may vary from different time span along with the land deposition and erosion. The change in land and it characteristics actively dominate the locality in terms of agriculture, fisheries etc. Mangrove prevents coastline from eroding away, so plantation or conservation of existing forest might be a cost effective and future proof strategy.

Abbreviations

SLC	Scan Line Corrector
TM	Thematic Mapper
ETM	Enhanced Thematic Mapper
MNDWI	Modified normalized water index
DN	Digital number
MIR	Mid infra-red band
κ	Kappa
p_0	Relative observed agreement among raters.
p_e	Hypothetical probability of chance agreement
GIS	Geographical information system
DN	Digital Number

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References

Addo, K. A., M. Walkden and J. P. t. Mills (2008). "Detection, measurement and prediction of shoreline recession in Accra, Ghana." ISPRS Journal of Photogrammetry and Remote Sensing **63**(5): 543-558.

Allison, M. A. (1998). "Historical changes in the Ganges-Brahmaputra delta front." Journal of Coastal Research: 1269-1275.

Anderson, J. R. (1976). A land use and land cover classification system for use with remote sensor data, US Government Printing Office.

Belal, A. and F. Moghanm (2011). "Detecting urban growth using remote sensing and GIS techniques in Al Gharbiya governorate, Egypt." The Egyptian Journal of Remote Sensing and Space Science **14**(2): 73-79.

Chavez, P. S. (1996). "Image-based atmospheric corrections-revisited and improved." Photogrammetric engineering and remote sensing **62**(9): 1025-1035.

Cohen, J. (1960). "A coefficient of agreement for nominal scales." Educational and psychological measurement **20**(1): 37-46.

Cowart, L., J. Walsh and D. R. Corbett (2010). "Analyzing estuarine shoreline change: A case study of Cedar Island, North Carolina." Journal of Coastal Research **26**(5): 817-830.

DARVISHZADEH, R. (2000). Change detection for urban spatial databases using remote sensing and GIS. Proceedings of ISPRS.

El-Asmar, H. and M. Hereher (2011). "Change detection of the coastal zone east of the Nile Delta using remote sensing." Environmental Earth Sciences **62**(4): 769-777.

Gens, R. (2010). "Remote sensing of coastlines: detection, extraction and monitoring." International Journal of Remote Sensing **31**(7): 1819-1836.

Hapke, C. J. (2011). "National assessment of shoreline change: Historical shoreline change along the New England and Mid-Atlantic coasts."

Khalil, G. M. (1993). "The catastrophic cyclone of April 1991: its impact on the economy of Bangladesh." Natural hazards **8**(3): 263-281.

Leatherman, S. P. (2001). "Social and economic costs of sea level rise." International Geophysics **75**: 181-223.

Li, X. and M. C. Damen (2010). "Coastline change detection with satellite remote sensing for environmental management of the Pearl River Estuary, China." Journal of Marine systems **82**: S54-S61.

Majlis, A. B. K., M. Islam, M. Khasru and M. Ahsan (2013). "Protected to Open Basin Depositional System: An Appraisal for the Late Quaternary Evolution of the Moheshkhali-Kutubdia Coastal Plain, Bangladesh." Bangladesh Journal of Geology **26**: 64-77.

Mars, J. and D. Houseknecht (2007). "Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska." Geology **35**(7): 583-586.

Morhange, C., J.-P. Goiran, M. Bourcier, P. Carbonel, J. Le Campion, J.-M. Rouchy and M. Yon (2000). "Recent Holocene paleo-environmental evolution and coastline changes of Kition, Larnaca, Cyprus, Mediterranean Sea." Marine Geology **170**(1): 205-230.

Pons, X. and L. Solé-Sugrañes (1994). "A simple radiometric correction model to improve automatic mapping of vegetation from multispectral satellite data." Remote sensing of Environment **48**(2): 191-204.

Ramsay, P. (1996). "9000 years of sea-level change along the southern African coastline." Quaternary International **31**: 71-75.

Ryu, J.-H., J.-S. Won and K. D. Min (2002). "Waterline extraction from Landsat TM data in a tidal flat: a case study in Gomso Bay, Korea." Remote Sensing of Environment **83**(3): 442-456.

Sarwar, M. G. M. and C. D. Woodroffe (2013). "Rates of shoreline change along the coast of Bangladesh." Journal of coastal conservation **17**(3): 515-526.

Schroeder, T. A., W. B. Cohen, C. Song, M. J. Canty and Z. Yang (2006). "Radiometric correction of multi-temporal Landsat data for characterization of early successional forest patterns in western Oregon." Remote sensing of environment **103**(1): 16-26.

Singh, A. (1989). "Review article digital change detection techniques using remotely-sensed data." International journal of remote sensing **10**(6): 989-1003.

Werner, A. D. and C. T. Simmons (2009). "Impact of sea-level rise on sea water intrusion in coastal aquifers." Groundwater **47**(2): 197-204.

White, S. A. and Y. Wang (2003). "Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline." Remote sensing of environment **85**(1): 39-47.

Yamano, H., H. Shimazaki, T. Matsunaga, A. Ishoda, C. McClennen, H. Yokoki, K. Fujita, Y. Osawa and H. Kayanne (2006). "Evaluation of various satellite sensors for waterline extraction in a coral reef environment: Majuro Atoll, Marshall Islands." Geomorphology **82**(3): 398-411.

Zhang, K., B. C. Douglas and S. P. Leatherman (2004). "Global warming and coastal erosion." Climatic Change **64**(1): 41-58.