Proceedings of the 7th International Conference on Asian and Pacific Coasts (APAC 2013) Bali, Indonesia, September 24-26, 2013

MORPHOLOGICAL CHANGES AND VEGETATION INDEX VARIATION ALONG THE WESTERN COASTAL ZONE OF BANGLADESH

A. Md. Shibly [1] and S. Takewaka [1]

ABSTRACT: Being a low laying deltaic country, morphological changes along the Bangladesh coastal zones are of major socio-economic and environmental concern. In this study, images of LANDSAT captured during 1989-2010 are analyzed to detect the variation of shoreline positions. Western coast has been divided into different segments and the rates of change of shoreline positions have been analyzed over three time periods 1989-2000, 2000-2006 and 2006-2010. AVHRR GIMMS and MODIS NDVI (Normalized Difference Vegetation Index) data sets are adopted during 1985-2006 and 2005-2010 respectively to monitor the long term variation of NDVI for the segments covered with mangroves. Fourier analysis has been performed to extract primary variation from NDVI time series. River discharge, water- and soil- salinity and wave hind cast (ECMWF) data has been also considered to infer the mechanism of shoreline dynamics and changes of NDVI variations. Every segment underwent rapid erosive changes during the periods of 1989-2000 and 2006-2010, compared to the period of 2000-2006, further segments covered with mangroves changed more rapidly than flat sandy beaches, contradicting the general consensus that mangrove stabilizes the land. Variation of NDVI showed a decreasing trend during the period of 1995-2000 and 2005-2010 at most of the locations, which may an indication of the decreasing tendency of vegetation activity of the area. Oppositely during the periods of 2000-2005, NDVI was in an increasing trend at all locations. Due to the construction of upstream barrage, fresh water discharge through the adjacent rivers decreased and water- and soil- salinity increased around the mangrove forest in the earlier period. This may impact mangrove ecosystem and accelerated the erosion. Shoreline of the western side of every segment faced larger changes compared to east side, which may be due to prevailing waves from south-south-west and consequent sediment transport from west to east.

Keywords: Shoreline, erosion, mangroves, NDVI, Bangladesh.

INTRODUCTION

Mangroves distribution can be used as an indicator of coastal changes in the tropical and many sub-tropical areas like Bangladesh (Blasco et al. 1996). Mangroves have a great ecological importance in shoreline stabilization, reduction of coastal erosion, sediment and nutrient retention, storm protection, flood and flow control, and water quality (Giri et al. 2007).

The objective of the study is i) to detect the shoreline position from satellite images, ii) to provide a regional overview of coastal accretion and erosion along the western-central coast of Bangladesh over three time periods, specially focused on the areas with mangrove forest, iii) to analyze the long term variation of Normalized Difference Vegetation Index (NDVI) derived from satellite data and iv) to identify the relationships between the morphological changes, vegetation index, river discharge, salinity and wave action.

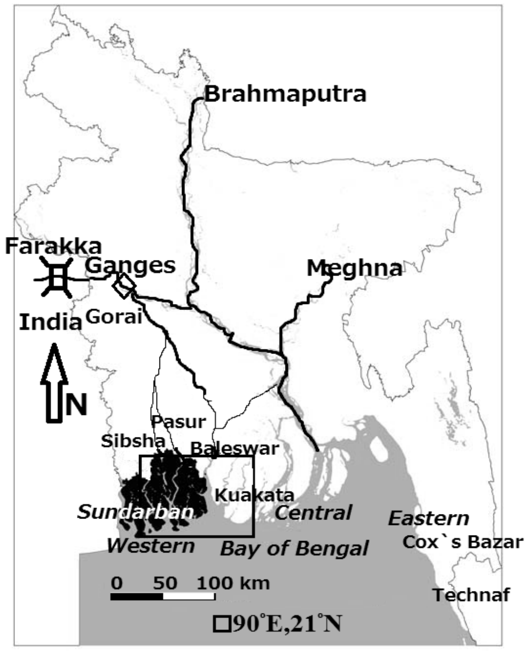

Fig. 1 Bangladesh map showing main rivers system. □ Wave hind cast data location. ♊ Barrage.◇ Harding Bridge. Solid box: study area (Fig. 2).

STUDY AREA

[1] Department of System and Information Engineering, University of Tsukuba, Tsukuba, Ibaraki 305-8577, JAPAN.

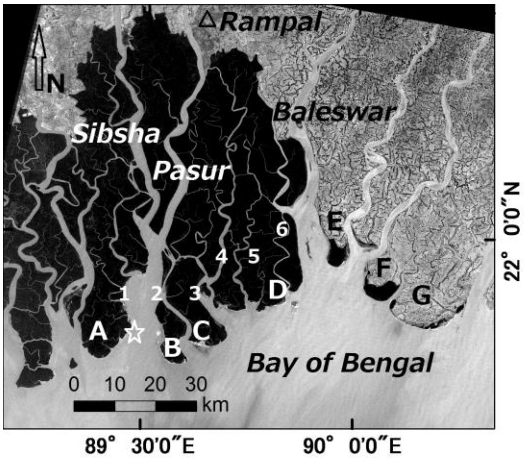

Fig. 2 Western coastal zone of Bangladesh and Segment A, B, C, D, F and G. Base image: Landsat 4, Band 1, 2 and 3, 1989/1/12. ☆ Tide station (Hiron Point). △ Salinity measurement station (Rampal). Points 1-6 are the NDVI analysis locations.

The southernmost part of Bangladesh is bordered by the 710-km-long coastline of Bay of Bengal. Figure 1 shows map of Bangladesh and Fig. 2 the study area, western-central coastal zones of Bangladesh (solid box in Fig. 1). To refine our understanding and discuss local situation, the study area has been divided into seven non-over lapping segments designated as A through G. The dark portions in Fig. 2 represent the land covered with mangrove forests, and the bright portions are agricultural lands or bare lands without mangrove forests.

Segments A, B, C and D are located in the western region and covered with mangrove forest popularly known as Sundarban (Beautiful forest) based on the named after the Sundari trees found in abundance there. Sundarban is located in the lower basin of the Ganges River and criss-crossed by numerous channels and creeks. The Gorai River (Fig.1), the main tributary of the Ganges River, connected Passur and Sibsha River with Ganges River, which are playing an influential role in the Sundarbans ecosystems. The Baleswer River flows through the eastern side of the segment D and falling in Bay of Bengal, receives water from Ganges-Brahmaputra-Meghna (GBM) River system. The soil characteristics of the western coastal zones are silty loams or alluvium. The area lies at 0.9 to 2.1 m above mean sea level. Mangrove supports feeding and breeding grounds for fish and shrimps species, enriching the area`s bio-diversity.

The central zone receives a large volume of discharge from the Ganges-Bhrahmputra-Meghna (GBM) river system, and the land is formed from silty deposition. Segments E, F and G located near the border of western and central region. Kuakata (G) has an attractive sandy beach popular with tourists located in this region. On the western side of segment G, the Baleswar River empties into Bay of Bengal, while the eastern side is dominated by the GBM system.

SATELLITE DATA PROCESSING

Shoreline Detection

The mid- and near-infrared spectral bands of satellite images have strong reflectance by soil and vegetation and absorbance by water, making it possible to separate the land from water and delineate the shoreline position (Kuleli, 2010). Alesheikh et al. (2007) showed that the mid-infrared band 5 of LANDSAT TM and ETM+ is suitable for extracting the land-water interface. In our study, 14 images from the LANDSAT USGS archive (http://glovis.usgs.gov/) have been analyzed to detect the variation of shoreline positions. Most of the images were acquired in dry season from November through December. Hourly tide level data from 1989-2010 were collected from BIWTA (Bangladesh Inland Water Transport Authority) for the nearby tide station Hiron Point and found that the tide level difference was approximately 2 m.

In the first step of image processing, geo-registration was done to adjust the geographic position of the images. Then edge detection was applied to the distribution of pixels intensities of band 5 images to locate the shoreline position. In each segment, southerly-facing shorelines were delineated at a spacing of 30 m alongshore from west to east. Finally, to refine the result, manual inspection has been carried out to clear the erroneous data. Shoreline changes were detected along transection line in N-S direction. The rate of shoreline variation was estimated over three periods1989-2000, 2000-2006 and 2006-2010 by linear regression of shoreline positions at every transect.

Variations of NDVI

NDVI is one of the techniques in the remote sensing field that can be used to monitor for the detection, description, quantification and monitoring land surface conditions and land surface vegetation variation (Giri et al. 2007). In this study, AVHRR GIMMS (1985-2006) (http:glcf.umd.edu/data/gimms/) and MODIS (2005-2010) NDVI data sets are used to analyze the long-term variation of NDVI.

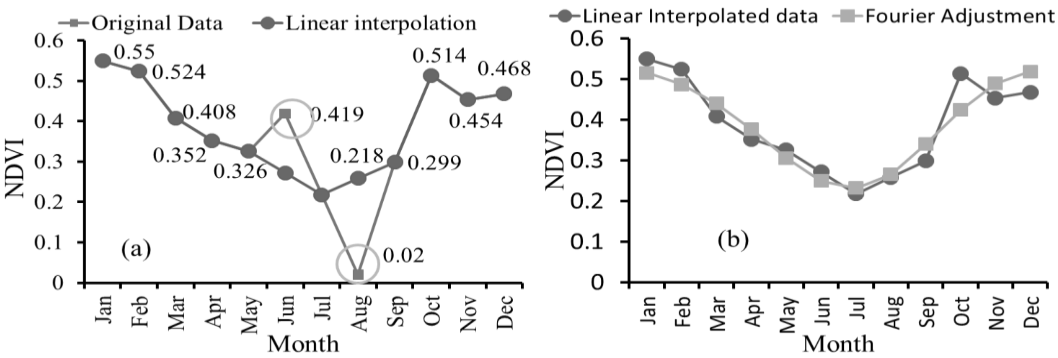

Fig. 3 (a) Original AVHRR GIMMS NDVI data of 1999 at segment A corrected by manual operation and linear interpolation, (b) Fourier adjustment of linear interpolated data.

The global coverage 8-km resolution 15-day composite data set (24 data in a year, 2 data for a month) of AVHRR (Advanced Very High Resolution Radiometer) GIMMS NDVI data (1981 to 2006) has been used for numerous local to global scale vegetation time series studies during recent year (Fensholt et al., 2009). Tucker et al. (2005) describe the GIMMS 15-day composite NDVI product description and processing details. From the whole globe GIMMS NDVI images (1985-2006), the pixel values near the segments (A, B, C and D) of Sundarban close to shoreline were picked up to analyze the long term changes of NDVI. In Fig. 2, the points 1-6 are the central locations of the picked up pixels. Monthly data were analyzed in this study.

MODIS subset NDVI data (2005-2010) have been collected from the ORNL DAAC (Oak Ridge National Laboratory Distributed Active Archive Center) to analyze the recent variation of NDVI. ORNL DAAC (http://daac.ornl.gov/cgibin/MODIS/GLBVIZ1Glb/modis_subset_order_global_col5.p) provides global NDVI data set with 250-m resolution and 16-day composite (23 data in a year) from 2000 to present. The ORNL DACC offer subsets of MODIS NDVI products for user-selected areas from one pixel up to 201*201 (worldwide). In our study subsets have been created considering the central latitude and longitude of GIMMS NDVI and its spatial size of 8-km. Average of NDVI from 32*32 pixels was provided from the data distributing system and monthly variation were analyzed.

There are some unexpected problematic data which may due to the changes of sensor of satellites, change of overpass time as well as lack of atmospheric condition and good pre-calibration (Fensholt et al. 2009). To create a consistent NDVI time series for both GIMMS and MODIS data, adjustment of the NDVI time series has been performed by two steps. In the first step, manual

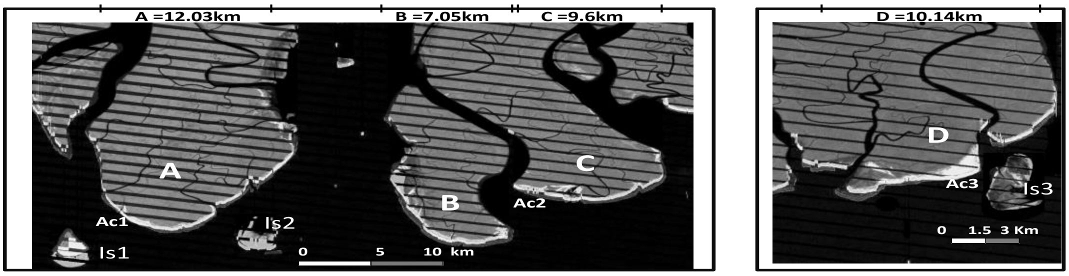

Fig. 4 Shoreline positions of 1989 and 2010 for segment A-D. Oblique strips of the images are due to the Landsat 7 malfunction. Red line shows the shoreline position at 1989 and green shows the shoreline position at 2010.

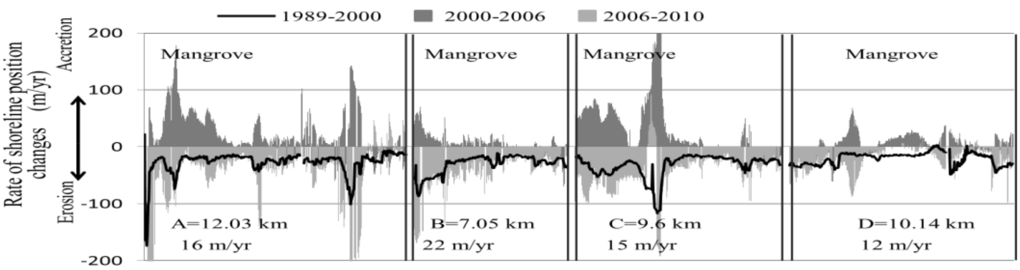

Fig. 5 Distribution of shoreline change rates of the three periods: 1989-2000 and 2000-2006 and 2006-2010 for segments A-D. Negative rate corresponds to erosion. Average change rate per year tabulated in the bottom panel.

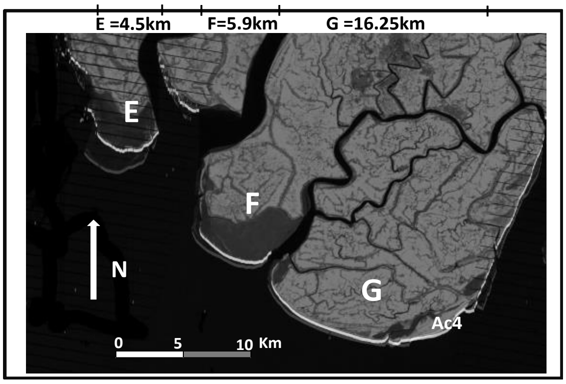

Fig. 6 Shoreline positions of 1989 and 2010 for segment E-G. Red line shows the shoreline position at 1989 and green shows the shoreline position at 2010.

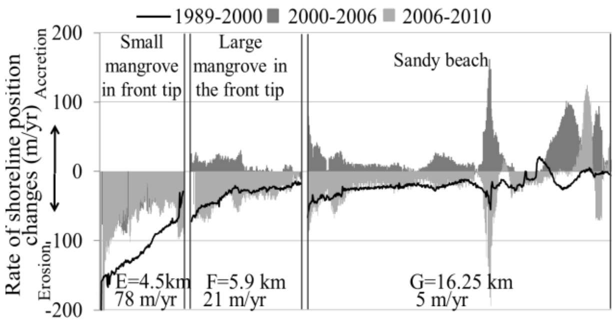

Fig. 7 Distribution of shoreline change rates of the three periods: 1989-2000 and 2000-2006 and 2006-2010 for segments E-G. Negative rate corresponds to erosion.

inspection has been carried out to correct the unexpected high and low data. Figure 3(a) shows an example of data replacement of sudden jump in the data sequence by linear interpolation. In the second step Fourier adjustment (with 1.0 and 0.5 year harmonics) has been performed to smooth the interpolated data received from first step assuming that the NDVI values at each location should have a smooth sequential variation (Fig. 3(b)).

RESULTS

Shoreline Changes

Figure 4 shows shoreline positions for 1989 and 2010 of segments A to D. Shorelines of segments A, B, C and D, covered with mangrove, were pushed back by erosion from their early positions. The shorelines of zones Ac-$_1$, Ac-$_2$ and Ac-$_3$ experienced no significant changes during the period of 1989-2010. Figure 5 shows the distribution of the shoreline change rates of three time periods 1989-2000, 2000-2006 and 2006-2010 for segments A to D. Among the three periods, earlier period (1989-2000) and recent (2006-2010) periods were suffering high erosion rates of shoreline positions. Conversely, the period of 2000-2006 was experiencing accumulations.

Figure 6 shows the shoreline positions for 1989 and 2010, and Fig. 7 shows the distribution of shoreline change rates for segment E to G. Most of the shorelines were seaward in 1989 compared to 2010 shorelines position. The shorelines of segment E and F, having small mangrove forests in their tips, have continuously retreated landward, except in the middle period where accumulations have been observed in segment F (Fig. 7). Segment E has experienced largest changes of its shoreline positions compared to other segments. Segment G, sandy beach has also lost land in the earlier and recent period, except the portion Ac-$_4$ on eastern side, gained land in the recent period also. In the middle period accretion has been observed at most of the locations of segment G (Fig. 6).

The rate of change of segments covered with mangroves (A, B, C, and D) was -17 m/yr, whereas that of flat sandy beach (G) was -5 m/yr (see Fig 5 and 7 bottom panel). This result is contradicting with the general consensus that mangroves stabilize the beach and resist against erosion. Maximum average change rate of -78 m/yr is observed in segment E where the tip of the land is also covered with mangroves.

From the result of the shoreline changes it has been also observed that the western side of every segment facing more changes as compared to the eastern side.

Variation of NDVI

Figure 8 shows the Fourier-adjusted time series of the NDVI of one point at the eastern side of segments A (Point 1 in Fig. 2). Figure 8 shows the NDVI distribution varies with an annual cyclic variation. Linear regression is applied to NDVI time series for the periods of 1985-1990, 1990-1995, 1995-2000 and 2000-2006 from AVHRR data, and 2005-2010 from MODIS data to find out the long term variation of NDVI along the study area. There is one year overlapping between every period in regression to make the trend analysis continuous. The solid line in Fig. 8 represents the trends lines for five time periods.

The statistics for the NDVI change rates for the different locations (Fig. 2) for all periods is shown in Fig. 9. In the periods of 1995-2000 NDVI change rates in most of the segments were slightly positive or negative.

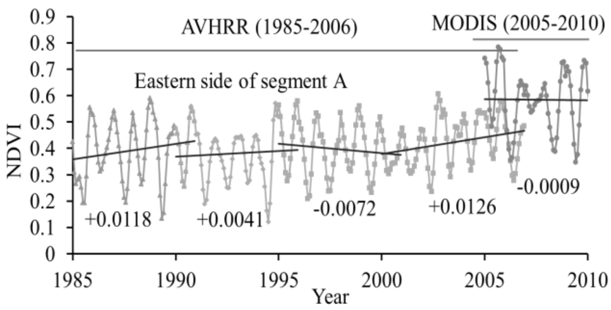

Fig. 8 Ions for the east side of segment A. Solid lines represent the trend lines.

In the next period 2000-2005, they become significantly

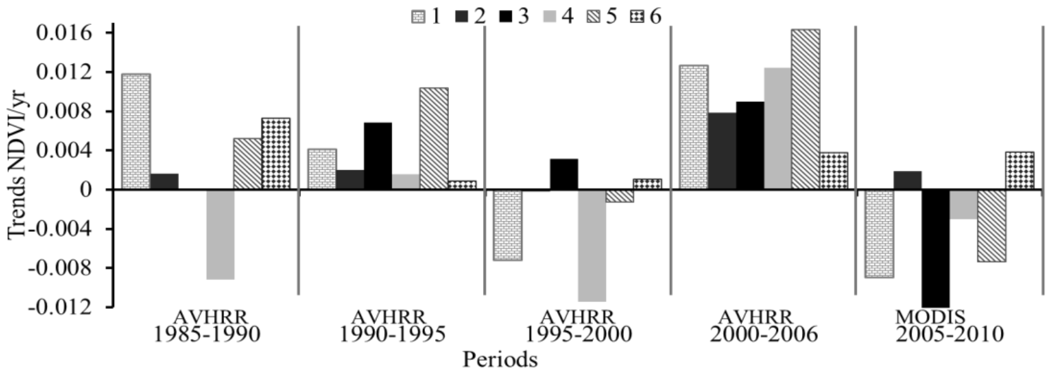

Fig. 9 NDVI change rates for periods of 1985-1990, 1990-1995, 1995-2000, 2000-2006 (AVHRR) and 2005-2010 (MODIS). 1-Segment A (east side), 2-Segment B, 3-Segment C, 4-Segemnt C&D, 5- Segment D (Middle), 6- Segment D (east side)

positive for the entire locations, which may be an indication of the improvement of the vegetation phenology of the area. The NDVI change rates in the latest period 2005-2010, turn to negative for most of the locations.

DISCUSSION

River Discharge, Salinity, and Morphological Changes of Mangrove Area

To discuss the impact of river discharge and salinity on the morphological changes and Vegetation Index over the mangrove area, river discharge and salinity data has been collected from the Bangladesh Water Development Board and from some literature.

The Ganges River dry season flows have been notably reduced from 1988-1998 since the construction of upstream Farakka barrage in India at 1975, consequently, salinity increased within the Sundarban area (Nazim and Anisul, 2010). The dry season flows is a matter of great concern in the Lower Ganges Basin as if the river flow was reduced to nil in the dry summer months it will increase the inland penetration of salinity. The unique habitat of the Sundarban depends on fresh water flow and salinity level in dry season to maintain ecological importance (Smith et al. 2009).

The fresh water flow through Sundarban increases due to the Ganges Water Sharing Agreement between India and Bangladesh at 1996 and after the completion of Gorai River Restoration Project (GRRP) at 1999, which dredged the riverbed of Gorai River to restore the dry-season's flow volume in this region. Figure 10 shows the Gorai River discharge and salinity variation of western zone at Rampal (Fig. 2) of Pasur River water. The figure shows that the Gorai River discharge in dry season increased and salinity dropped down significantly after the completion of GRRP in 1999. But later on after 2005, the salinity again increased at an alarming rate as the river discharge in the recent time is going to nil as like the period of 1988-1998.

The possible effects of increased salinity on the ecosystem of the Sundarban are the dying of tops of Sundari trees, retrogression of forest types, slow forest growth, and reduced productivity of forest sites (Islam and Gnauck, 2008). Decreasing NDVI trends observed in the periods of 1995-2000 and 2005-2010 are may be due to this fact.

Increase salinity (basically sodium) concentration disperses clay soil through reduction of infiltration and increasing of runoff (Hanson et al, 1999). Increase in soil- and water- salinity may lead to coastal retreat and weakening of mangrove area along with shoreline in the period of 1989-2000 and 2006-2010.

Sandy beach G is dominated by the GBM system and this portion was not affected by the reduction of fresh water flow of Ganges River as well as increase of salinity. Also salinity has less impact on the sandy soil in terms of dispersion. This may one of the reasons for low erosion rate of segment G.

Erosion at the Western Faces of the Segments

To find out the effect of wave action over erosion and accretion along the coast, wave hind cast data for the period of 1989-2010 have been analyzed. Hind cast wave data e.g. significant wave height, wave period, and wave direction have been taken from the ECMWF ERA-

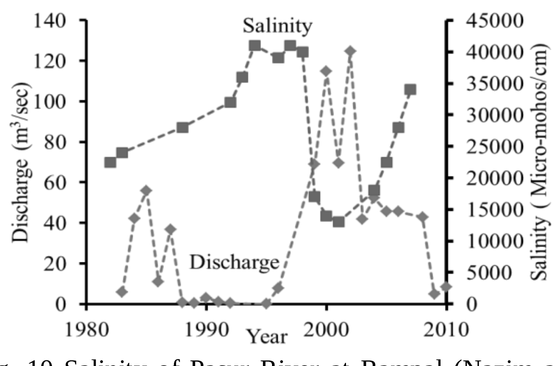

Fig. 10 Salinity of Pasur River at Rampal (Nazim and Anisul, 2010) and Gorai River discharge at Month of April (BWDB).

Interim archive (http://data-portal.ecmwf.int/data/d/interim_daily/).

Figure 11 displays significant wave height and wave direction for the period 1989-2010 at a grid 90º E, 21º N, which is the closest data to segments E, F and G (See Fig.1(a)). Incident waves from the south-south-west are dominating along the coast. The prevailing waves may yield sediment transport from west to east which supports the fact that shoreline change rate of the west side of every segment is facing larger changes compared to the east side. Further, the accumulation zones Ac-$_1$ and Ac-$_2$ are in the western face of the segments A and C, and are in the down-wave of the prevailing waves sheltered behind island Is1 and segment B, respectively (Fig. 4).

CONCLUSION

Satellite remote sensing data have been analyzed to identify the morphological changes at the western coastal zone of Bangladesh. Shoreline changes experienced erosion in the past period (1989-2000) and recent period (2006-2010). On the contrary in the period of 2000-2006 accretion has been observed at most of the locations. Shoreline change rates at mangrove portion (Segment A to D) were larger compared to sandy open beach (Segment G), contradicting with general consensus that mangrove stabilize the land. Shoreline change rates of every segment are higher at western face than the eastern faces, which may due to the south-south-wave action.

Analysis of NDVI variation of Sundarban near shore showed that NDVI had decreasing trends in the period of 1995-2000 and 2005-2010 and increasing from 2000-2005.

The Ganges dry season flows have been notably reduced since the construction of upstream barrage, consequently, salinity increased within the mangrove area in the period of 1989-2000 and 2005-2010. High salinity may disperse clay soil, lead the coast to retreat and deteriorate the forest growth. Morphological study and vegetation analysis indicated that higher erosion rates and decreasing trend of Vegetation Index were observed at the high salinity periods (1989-2000 and 2005-2010). Sandy beach (G) is not affect by the lower Ganges discharge and high salinity. Less erosion rate was observed compared to the Mangrove area (segment A-D) which may due to this reason.

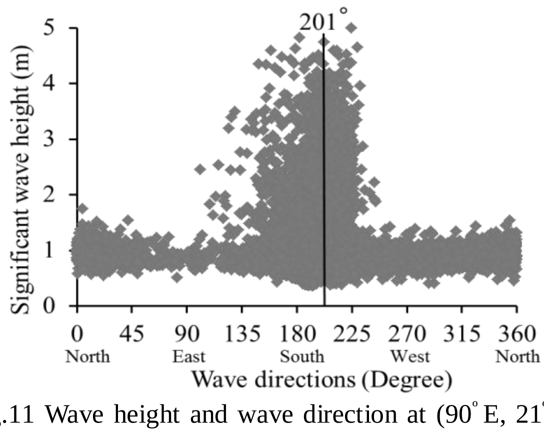

Fig.11 Wave height and wave direction at (90˚E, 21˚N) for the period of 1989-2010 retrieved from ERA-Interim. Solid line represents center of gravity of the distribution

REFERENCES

Alesheikh, A. A., Ghorbanali, A., Nouri, N. (2007). Coastline change detection using remote sensing. Int. J. Environ. Sci. Tech. 4(1): 61-66.

Blasco, F., Saenger, P. and Janodet, E. (1996). Mangrove as indicators of coastal change. Catena. 27: 167-178.

Fensholt, R., Rasmussen, K., Nielsen, T. and Mbow, C. (2009). Evaluation of earth observation based long term vegetation trends-Inter comparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOT VGT data. Remote Sensing of Envi. 113: 1886–1898.

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 1973 to 2000. Estuarine, Coastal and Shelf Science. 73: 91–100.

Hanson, B., Grattan, R., and Fulton, A. (1999). Agricultural Salinity and Drainage. University of California Irrigation Program. Davis.

Islam, S.N., and Gnauck, A. (2008): Mangrove wetland ecosystems in Ganges-Brahmaputra delta in Bangladesh. *Front. Earth Sci.*, Vol 2(4), 439.448.

Kuleli, T. (2010). Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey. Environ Monit Assess. 167: 387-397.

Nazim, U. and Anisul, H. (2010). Salinity response in southwest coastal region of Bangladesh due to Hydraulic and Hydrologic parameters. Int. J. Sustain. Agril. Tech. 6(3): 01-07.

Smith, B. D., Braulik, G., Mansur, R., Ahmed, B. (2009). Habitat selection of freshwater-dependent cetaceans and the potential effects of declining freshwater flows and sea-level rise in waterways of the Sundarbans mangrove forest, Bangladesh. Aquatic Conserv: Mar. Freshw. Ecosyst. 19: 209–225 (2009).

Tucker, C. J., Pizon, J. E., Brown, M. E., Slayback, A., Pak, W., Mahoney, R., Vermote, E. F., and Saleous, N. E. (2005). An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. International Journal of Remote Sensing. 26(20): 4485-4498.