Recent coastline changes at the eastern part of the Meghna Estuary using PALSAR and Landsat images

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Abstract: In the present paper, we have focused on the recent coastline changes at the eastern part of the Meghna Estuary of Bangladesh through the application of PALSAR (The Phased Array L-band Synthetic Aperture Radar) and Landsat images. The area under concern is very dynamic where the combined processes of erosion and accretion take place under the influence of river discharge with heavy sediment load, wind waves and tides. It falls under the macro-tidal zone with tidal range varying from 4m to 6m or even higher. Many parts of the area is covered with intertidal mudflats. They are inundated during the high tides and get exposed during the low tides. So for the detection coastline change consideration of tidal phase is quite important which has been done in the present study. Coastline change from the year 2007 to 2013 has been presented in this paper. From the analyses of satellite images the areas of erosion and accretion of the four major offshore islands have been calculated during the above mentioned period. It has been found that the annual rate of accretion of Urir Char island has decreased from 5.84 km² per year between 2007~2010 to 1.05 km² per year between 2010~2013. On the other hand, Sandwip island has been eroding at a higher rate of 3.15 km² per year between 2010~2013 compared to 0.34 km² per year between 2007~2010. Overall, the total area of Urir Char, Sandwip and Jahajir Char island increased by about 120 km² from 2007 to 2013, mainly contributed by the drastic expansion of Jahajir Char island during this period.

1. Introduction
The detection of coastline and its changes is an important constituent for the engineers, scientists and implementing agencies involved in coastal management. The position of the coastline and its historical change can provide important information for the design of coastal protection works, coastal
development plans, and the calibration and verification of numerical models [1]. So, the overall management process has to be supported by a monitoring component of the shoreline which will require repeated surveys to take into account of the seasonal variability, storm events and other natural phenomena. The monitoring process must ensure a good compromise between accuracy, cost and time. This is why, during the recent past, for the purpose of coastline monitoring remote sensing technique is becoming increasingly popular (as shown by [2]~[7]) compared to GPS survey, aerial photography, airborne videography and video systems. It allows very quick data acquisition and processing compared to photogrammetry. At the same time satellite images with high spatial resolution provide comparable accuracy with other survey methods. The satellites with high temporal resolution have a short revisiting time (a few days) which allows to carry out monitoring studies of the area under examination, by means of images acquired at different times.

The coastlines around the Meghna Estuary of Bangladesh (figure 1) experiences dynamic morphological changes due to heavy sediment discharge from the combined flow from the Ganges, Brahmaputra and Upper Meghna Rivers with annual rate of nearly billion tons. Movement of coastlines at this scale cannot be found at any other parts of the world [8].

![Figure 1. The Meghna Estuary and the study area (source: Google Earth).](image)

Based on satellite images for the period of 1973~2000, Meghna Estuary Study [9] estimated the erosion and accretion in the region as 863.66 km² and 1371.68 km², respectively, which gives a net accretion of
508.02 km² area at a rate of 18.8 km² per year. As can be seen from figure 1, a number of small to large islands are located at the river mouth of the Meghna Estuary. Most of these islands are surrounded by intertidal mudflats. These mudflats are inundated during the high tide and get exposed during the low tide. In the satellite images acquired during the low tide the shallow areas appear as murky patches around the islands and adjacent to the coastlines. As already mentioned the study area under investigation receives huge amount of sediments from the rivers. That is why even sub-tidal areas in the Meghna Estuary exhibit similar murkiness when observed from the satellite images. So coastline detection becomes ambiguous. Again the very shallow water areas over the mudflats may appear as dark patches in some satellite images, for example for PALSAR images [10]. The process of land accretion is dominant in the region of the Meghna Estuary. About one fifth of the original supply of 1,100 million tons is retained in the Meghna Estuary and forms the material for land accretion in the central part of the coastal zone [1].

High-tide coastline method have been applied by [11] to study the erosion along the Kuakata coast located outside the Meghna Estuary area in the western side. Erosion and accretion along some of the coastal islands located in the central and western part of Meghna Estuary has also been studied by [12] for a period of 34 years (1977-2010) by using Landsat satellite images. Landsat images have also been used to study the morphological changes in the western and central part of the coastal areas of Bangladesh by [13] including the effect of mangrove forests for erosion control in these coastal belts. Another intriguing study was done by [14] involving remote sensing technology which focused on the transportation, distribution and deposition of suspended sediments in the Meghna Estuary through the application of Landsat TM images.

In this study, use of high-resolution image is important because it can help to distinguish the border between land and sea precisely. To find seasonal and yearly trend, comparing as many satellite images as possible is also essential. For this purpose, PALSAR images are suitable because it has not only a high-resolution mode but also its images are more frequently taken than other satellites of this kind. Its maximum ground resolution of PALSAR is 7m, and twenty-one images are available during the period 2007-2011. PALSAR is equipped with ALOS (The Advanced Land Observing Satellite), which was developed in Japan. As there is no more images available from PALSAR after 2011, we have used recent Landsat images to further update the erosion accretion scenario in the study area.

The overall goal of the present research is to develop an efficient method in order to assess the morphological changes in the Meghna Estuary area of Bangladesh. This involves processing and analyses of satellite images for coastline updating, validation of a numerical model for flow simulation in the estuary and also simulation of erosion-sedimentation processes in the estuary. The present paper focuses on the satellite data analyses to extract the amount of erosion and accretion at the eastern part of Meghna Estuary.

2. Methodology
As already mentioned, during the period of January 2007 to April 2011 a total of twenty-one PALSAR images were acquired under the present study. All the images are from Advanced Land Observing Satellite’s Phased Array L-band Synthetic Aperture Radar (ALOS-PALSAR) and they have been collected from Japan Aerospace Exploration Agency (JAXA). All the products used for the study are
Level 1. Polarization of the images used for the present study are either HH or (HH+HV). The tidal phase at the time when these images were collected does not allow all these images to be compared directly. The existence of large intertidal mudflats and sediment laden estuarine flow makes the coastline detection process quite difficult. To overcome this problem only images collected near the peak of high tide period were analyzed.

A harmonic analysis was performed following a technique proposed by [15] to predict the tidal condition of the area at the time periods when the satellite images were available. In this analysis, the tidal constituents were calculated from observed data. The data were collected during Meghna Estuary Study during 1997 at the east of Hatiya island. The images which were acquired around the peak of high tides were then selected with the help of the results from harmonic analyses. The selected PALSAR images were acquired on 15 January 2007 at 16:29:50 LST and 10 March 2010 at 16:31:19 LST. The Landsat image at a recent date: 30 October 2013 at 10:20:29 LST was also selected fulfilling this criteria. Another Landsat image was selected on 12 September 2013 at 10:20:46 LST to identify the extent of intertidal mudflats around the major offshore islands at the eastern part of the Meghna Estuary. Figure 2 shows the simulated tidal water levels on 15 January 2007 and 10 March 2010 where the satellite data (PALSAR) acquisition times are marked by the dots. As can be seen both the images were acquired near the peaks of high tide periods.

![Figure 2](image_url)

**Figure 2.** Predicted tidal water levels on 15 January 2007 and 10 March 2010; dots indicate the satellite image acquisition time.

Similarly, figure 3 shows simulated tidal water levels on 12 September 2013 and 30 October 2013 where the satellite data (Landsat) acquisition times are marked by the dots. As can be seen the image on 12 September 2013 was acquired near the lowest water level. So it should include maximum amount of intertidal mudflats around the study area. The other image on 30 October 2013 was acquired near the peak of high tide periods, so it should be comparable to the previously acquired PALSAR images to evaluate the erosion and accretion in the study area.

For PALSAR image processing, first each raw image file was geocoded to geographic (latitude-longitude) system by ASF MapReady, a freeware, at desired resolution and were converted to geo-tiff file format. Then adjacent images of the same time have been combined by using ARC-GIS software. Next the coastlines were identified through visual interpretation which involves careful image
interpretation. Finally, for the purpose of calculating erosion and accretion desired images were overlaid to extract the area of erosion and accretion. Same procedures were repeated for each Landsat images except the use of ASF MapReady.

**Figure 3.** Predicted tidal water levels on 12 September 2013 and 30 October 2013; dots indicate the satellite image acquisition time.

### 3. Results and Discussion

In this section, first the areal extent of the four major islands are determined during the low and high tide periods of September and October, respectively, of 2013 to extract the inter-tidal mudflats around the islands. Next, the erosion and accretion around these islands are obtained from the comparison of high-tide coastlines from the years of 2007, 2010 and 2013.

#### 3.1 High and low tide area and extent of mudflat detection

Table 1 shows the high and low tide areas and extent of intertidal mudflats of the four major offshore islands: Urir Char, Sandwip, Jahajir Char and Hatiya islands located at the eastern part of the Meghna Estuary. Clearly all the islands have significant proportion of intertidal mudflats, highest proportion being around Sandwip island (15%) and the lowest around Urir Char island (8%). Areal extent is highest around the Hatiya island (52km$^2$).

**Table 1.** Area in km$^2$ of four major islands and their intertidal mudflats.

| Islands    | Area (km$^2$) on 12 Sep 2013 | Area (km$^2$) on 30 Oct 2013 | Area (km$^2$) of Intertidal Mudflat |
|------------|-------------------------------|-------------------------------|-----------------------------------|
| Urir Char  | 118.82                        | 128.36                        | 9.54                              |
| Sandwip    | 210.66                        | 242.30                        | 31.64                             |
| Jahajir Char| 217.50                        | 247.45                        | 29.95                             |
| Hatiya     | 431.41                        | 483.14                        | 51.72                             |
Figure 4 shows the coastlines extracted around Urir Char and Sandwip islands on 12 September 2013 and 30 October 2013 representing low tide shoreline and high tide shoreline, respectively. From the figure it is evident that Urir Char have intertidal mudflats around its three parts: east, north and west. Along the south part of Urir Char as the coastline is almost the same during high tide and low tide periods, indicating that there is no intertidal mudflats along the southern part of Urir Char. This was also verified during the field trip to Urir Char during December 2012, as shown in figure 5.

![Figure 4. Coastlines extracted around Urir Char and Sandwip islands on 12 September 2013 (low tide) and 30 October 2013 (high tide).](image)

![Figure 5. Left: intertidal mudflats along the northern part of Urir Char and right: relatively steep slope along the southern part of Urir Char island.](image)
Sandwip island, on the other hand, have large mudflats mainly at its north and south coasts. There is a small portion of mudflat along the middle part of its east coast. Along the rest of the Sandwip coast there is no further existence of mudflats.

![Figure 6. Coastlines extracted around Jahajir Char and Hatiya islands on 12 September 2013 (low tide) and 30 October 2013 (high tide).](image)

Figure 6 shows the coastlines extracted around Jahajir Char and Hatiya islands on during low and high tide periods. From the figure it is evident that Jahajir Char island have most of its intertidal mudflats along its southern and south-eastern part. Along its north and north-west coasts there is no mudflats. Hatiya island also have large mudflats mainly at its south and south-east coasts and around the small islands near it. The small islands (including Nijhum Dwip island) at the south of Hatiya island are included as part of the Hatiya island as they almost get connected with the main Hatiya island during low tides. There is a small portion of mudflat along the middle part of its east coast. Along the rest of the Sandwip coast there is no further existence of mudflats.

3.2 Erosion and accretion around the major offshore islands

Table 2 shows the high tide areas of the four major islands at the eastern part of the Meghna Estuary during 2007, 2010 and 2013, extracted from PALSAR and Landsat images. These areas exclude the intertidal mudflat areas. The available PALSAR images do not cover the entire part of the Hatiya island. So the total area of the island is only obtained for 2013. Negative sign indicates erosion. The table shows that the overall rate of accretion of Urir Char island has slowed down to 1.05 km$^2$ per year during the recent three years, which was previously 5.84 km$^2$ per year between 2007~2010. On the other hand, Sandwip island has been facing erosion at a higher rate of 3.15 km$^2$ during the recent three years compared to the previous 0.34 km$^2$ per year. Jahajir Char island has been accreting at a slower rate in
recent three years at a rate of 7.78 km$^2$ per year compared to the previous huge rate 40.55 km$^2$ per year mainly due to the erosion from the Char Jublee located at the northern part of Jahajir Char island.

**Table 2.** Total area and change of area in km$^2$ of four major islands.

| Islands      | Total area (km$^2$) | Area change (km$^2$) |
|--------------|---------------------|----------------------|
|              | Jan 2007 Mar 2010   | Oct 2013 '07-'10 '10-'13 |
| Urir Char    | 102.40 115.05       | 118.82 12.65 3.77     |
| Sandwip      | 222.66 221.93       | 210.66 -0.73 -11.27   |
| Jahajir Char | 101.77 189.63       | 217.50 87.86 27.88    |
| Hatiya       | -                   | 431.41 - -            |

Figure 7 shows the coastlines extracted around the Urir Char and Sandwip islands during 2007, 2010 and 2013. It is evident that Urir Char is accreting along its three coasts: east, north and west and along the south, south-east part it is eroding. It appears that the intertidal mudflats are having an impact on the accreting process as accretion is taking place in those areas. The Sandwip island is primarily eroding along its south coast and north-east coast, while it is accreting along the north-west and middle part of east coast.

**Figure 7.** Coastlines extracted around Urir Char and Sandwip islands on 2007, 2010 and 2013.
Figure 8 shows the coastlines extracted around the Jahajir Char and north part of Hatiya islands during 2007, 2010 and 2013. It is evident that Jahajir Char island is accreting along south, south-east and south-west coasts. It appears that major accretion took place during 2007~2010 when parts of the Char Jublee from the northern part was attached to the Jahajir Char island. Jahajir Char is also facing some erosion along its northern part. Northern part of Hatiya island is clearly facing erosion at a rate of about half a km during 2007~2010 and 2010~2013.

![Figure 8. Coastlines extracted around Urir Char and Sandwip islands on 2007, 2010 and 2013.](image)

Table 3 shows the total erosion and accretion during the study period at the four offshore islands at the eastern part of Meghna Estuary. It appears that in Urir Char island the rate of erosion has become higher in recent years while the rate of accretion has dropped. Similar trend is also observed at Sandwip and Jahajir Char islands. But still the rate of accretion in these four islands is much higher than the rate of erosion.

**Table 3.** Total erosion and accretion area in km² of four major islands.

| Islands       | Erosion area (km²) | Accretion area (km²) |
|---------------|--------------------|----------------------|
|               | 2007~2010  | 2010~2013 | 2007~2010 | 2010~2013 |
| Urir Char     | 3.31       | 5.63      | 15.92    | 10.26     |
| Sandwip       | 9.08       | 11.49     | 8.62     | 1.46      |
| Jahajir Char  | 4.16       | 16.36     | 90.77    | 45.90     |
| North Hatiya  | 3.12       | 4.73      | -        | -         |
Overall, Meghna Estuary is known as an area where accretion dominates [16]. During the recent three years it appears that the rate of accretion has slowed down at the four major offshore islands at the eastern part of the Meghna Estuary. The newly accreted islands located south of Jahajir Char island between Sandwip and Hatiya islands may increase the overall rate of accretion in the eastern part of the Meghna Estuary.

4. Conclusions
High resolution satellite images from PALSAR and Landsat have been analyzed to study the erosion and accretion phenomena in the Meghna Estuary. The estuary is known as an area where accretion dominates. During the recent three years it appears that the rate of accretion has slowed down at the four major offshore islands at the eastern part of the Meghna Estuary. It has been found that the annual rate of accretion of Urir Char island has decreased from 5.84 km$^2$ per year between 2007–2010 to 1.05 km$^2$ per year between 2010–2013. On the other hand, Sandwip island has been eroding at a higher rate of 3.15 km$^2$ per year between 2010–2013 compared to 0.34 km$^2$ per year between 2007–2010. Overall, the total area of Urir Char, Sandwip and Jahajir Char island increased by about 120 km$^2$ from 2007 to 2013, mainly contributed by the drastic expansion of Jahajir Char island during this period.

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