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RESEARCH PAPER

Recent Erosion-Accretion scenario of Hugli estuary using geoinformatics

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ABSTRACT

The present study shows coastal morphological changes in a complex dynamic coastal zone like Hugli Estuary. This is an area where eustatic, isostatic and tectonic forces control the significant geomorpholoical changes in a combine manner. The prime objective of the research work is to detect and estimate of the recently developed zones under erosion and accretion of the estuary using a series of multi-temporal satellite images namely IRS 1C 28/11/99, IRS 1C 27/03/2000, IRS 1D 19/02/2001, IRS P6 20/11/2005 and IRS P6 28/02/2008. The entire analytical research work has been performed under a sophisticated remote sensing and GIS platform to achieve higher accuracy and precision in computation. The final output reveals that in very recent years, some parts of the area reflect severe rate of erosion while the rest of the area indicates high rate of accretion. Frequent tides with severe cyclones and soil erosion due to large scale deforestation are strongly responsible for the land use change for the entire study area in recent years.

Key Words : Eustatic, Geomorphology, GIS, Multi-temporal, Remote sensing

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The Hugli estuary is a highly dynamic coastal zone. It faces remarkable tidal and cyclonic activities throughout the year. Hence, it requires continuous monitoring and updating of tidal information. Recently, remote sensing and GIS techniques help to monitor the dynamic environment. The study area is located in West Bengal covering parts of South 24 Parganas Purba Medinipur districts. The study area extends between 21º29’54”N and 22º19’26”N latitudes, and 87º46’13”E and 88º58’49”E longitudes.

Bifurcation of flood flow took place near the tail of Nayachara Island (southern end) whereas the adverse bed slope and undesired shoaling at Jiggerkhali Flat at the northern end of Nayachara Island proved to be the major resistance for ebb flow causing change in flow path. The same resistance attributes for damping effect and gradual cessation of flood flow through Haldia channel. Other critical geomorpholgical changes occurring within the study area are :

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- Bank erosion in right bank of Haldi river as well as Hugli river near Sondia column.
- Extension of nayachara Tail and consolidation of westerly and easterly sands near the tail and its vertical growth.
- Changes in shape, size and orientation of Gutter alongwith Kaukhali and Mizzen group of sand around secondary channel.

The details regarding the extension of Nayachara Tail (in southern direction), its peripheral and vertical growth, erosion of Ghoramara Islands, erosion and accretion in Sagar Island, growth and decay of Balari bar, status of Rangafalla Channel, Eden Channel and Haldi river etc. are analysed by Image Analysis. Remote Sensing technique (*viz.*, interpretation of satellite data along with synchronous hydrological condition) is applied to the study area over the year 1999-2008. The visual interpretation as well as digital image processing technique is applied for evaluating the following features:

Several works have been done earlier on this context. An assessment has been made on land use dynamics and shoreline changes of Sagar Island using remote sensing techniques (Ghosh *et al.*, 2001). An estimation has been done on the erosion process of the coast of Sagar Island (Gopinath and Seralathan, 2005). A research has been performed on space and time related changes of land surface parameters in the Red river of the north basin (Melesse, 2004). Apart from these, an evaluation has been made on the coastal erosion due to wave dynamics operative in Sundarban delta (Purkait, 2008). Moreover, Landsat TM data has been used in order to design coastal morphological mapping around the Gulf of Khambhat (Shaikh *et al.*, 1989). A very recent attempt was done to estimate the land use change of Hugli estuary using Fuzzy C-Mean algorithm (Mondal *et al.*, 2011). Another successful research work has been done on the ever changing physical regime of the inner part of Hugli estuary (Banerjee *et al.*, 2013). A fantastic overview has been published analysing the tidal action and prediction in Hugli estuary (Rose *et al.*, 2015). Besides, a very new research activity has been made to assess the morphodynamic change of parts of Hugli estuary (Mondal *et al.*, 2015). Balari bar, a significant landmass of Hugli estuary has come under recent morphological changes (Guha and Dey, 2015). A remarkable work has been done on the morphological changes of Ghoramara island during 1972-2010 (Adarsa *et al.*,2012). An attempt was taken to delineate the morphological change of islands of Ganga delta region (Chakraborty, 2013). Study on beach accretion and erosion helped a lot for coastal erosion analysis (Anwar *et al.*, 1979 and Mallik *et al.*, 1987). River and channel migration is a beneficial work to carry on the present research (Philip *et al.*, 1989 and Ramasamy *et al.*, 1991). A coastal vulnerability index was estimated for Mangalore coast (Hegde and Reju, 2007). A very recent research work was done on decadal changes in shoreline patterns in Sundarbans (Chatterjee *et al.*, 2015).

RESEARCH METHODOLOGY

The main objective of the present study is to monitor the recent coastal morphological changes observed in the Hugli estuary using satellite images of successive years (Jensen, 2005). The techniques of remote sensing and geographical information system are used for the visual interpretation and understanding the recent morphological changes arising out for variation in erosion and accretion of the landmass. The morphological status of the estuary is overviewed

from the images covering the stretch Kulpi to Sagar Island covering the Balari bar, Haldia channel, Rangafalla channel, Eden channel, Nayachara, Ghoramara and Sagar Islands between the period 1999 to 2008. The images considered for comparison are IRS 1C 28/11/99, IRS 1C 27/03/2000, IRS 1D 19/02/2001, IRS P6 20/11/2005 and IRS P6 2008.

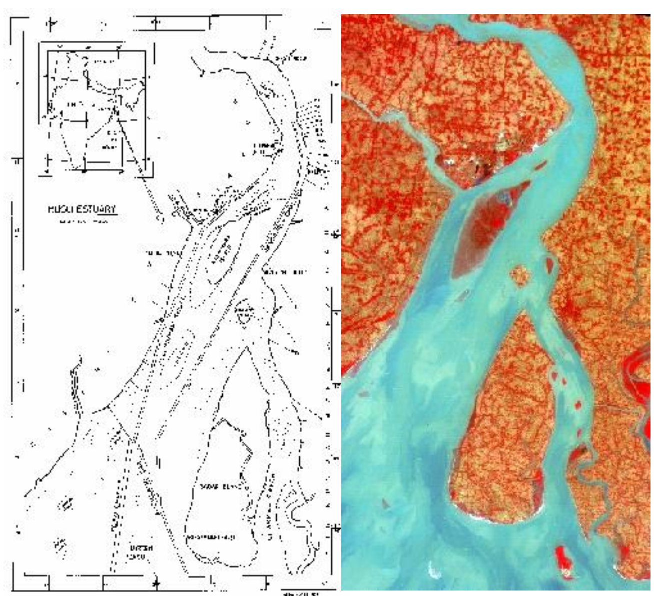

Fig. A : Location of the study area

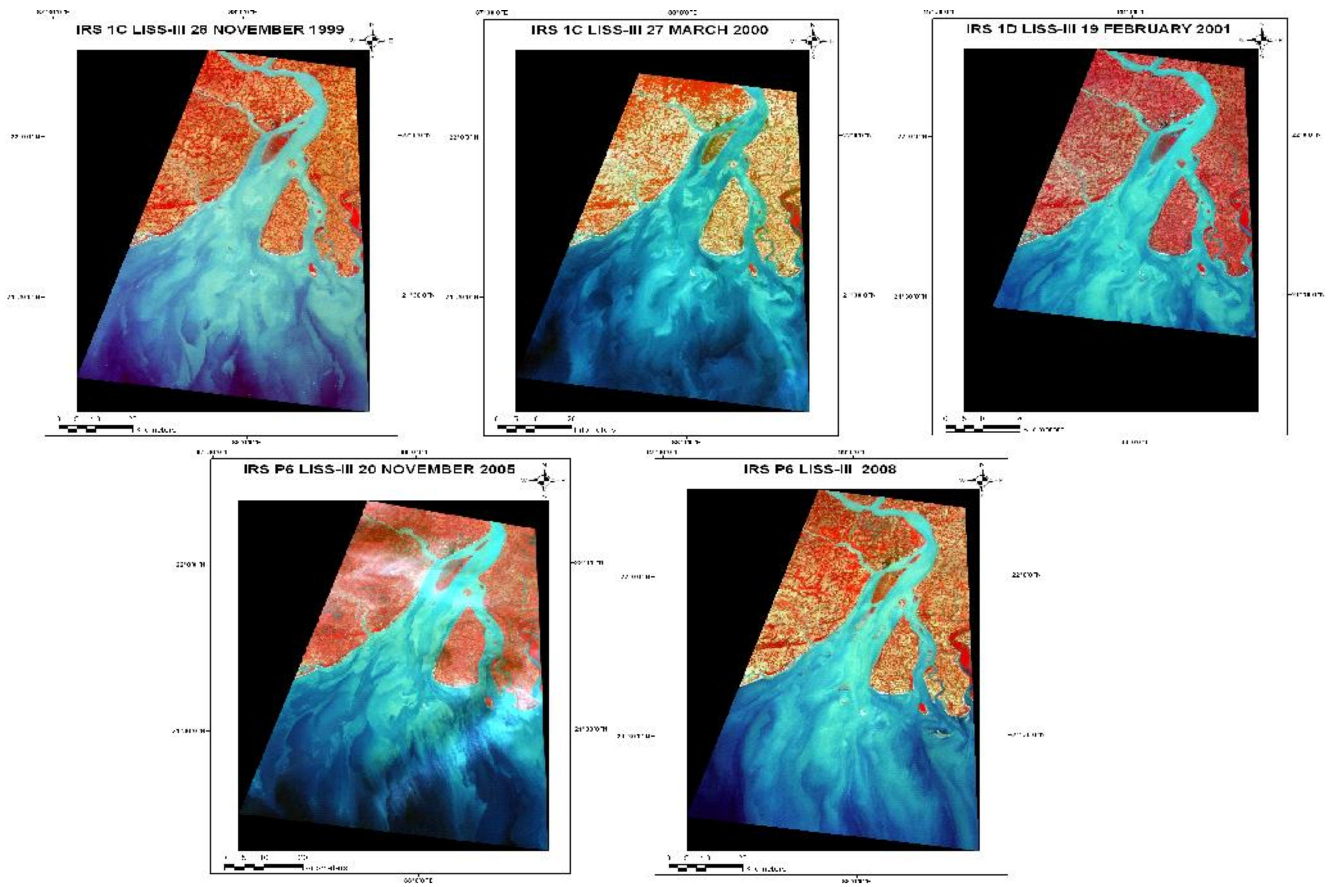

Fig. B : Multi-temporal satellite imageries of Hugli estuary (1999, 2000, 2001, 2005 and 2008)

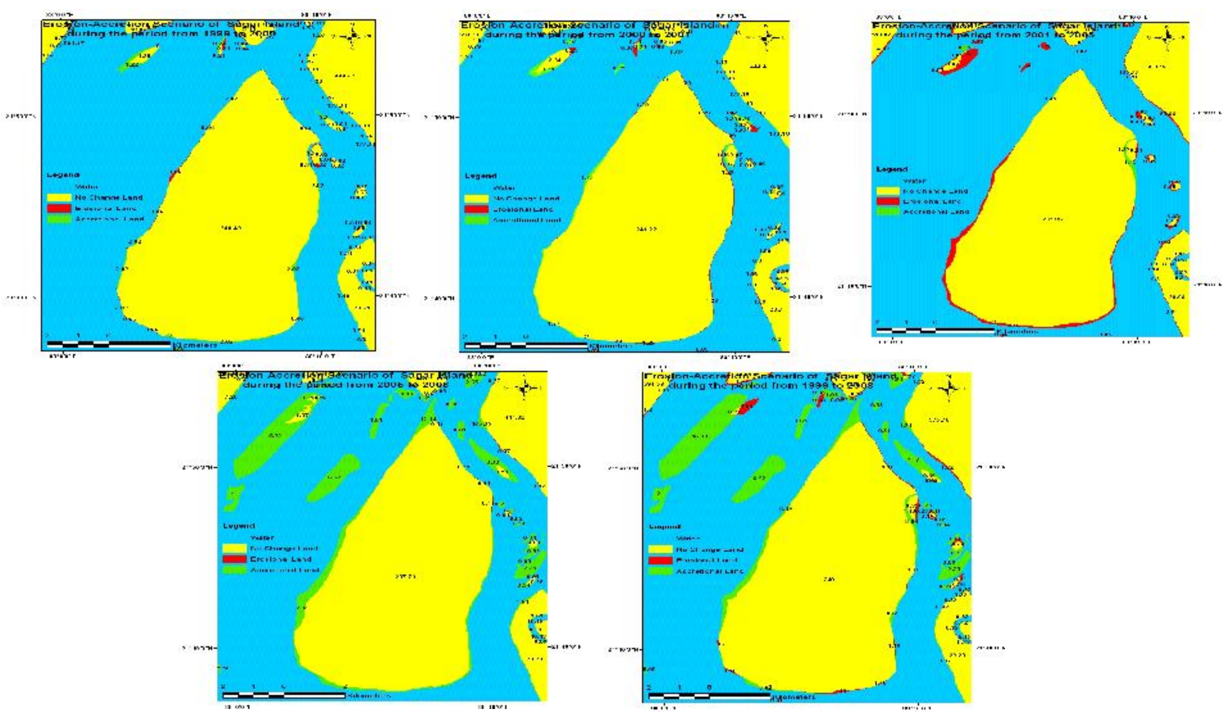

Fig. C : Stable and changed landmass (area in sq km) of Sagar Island

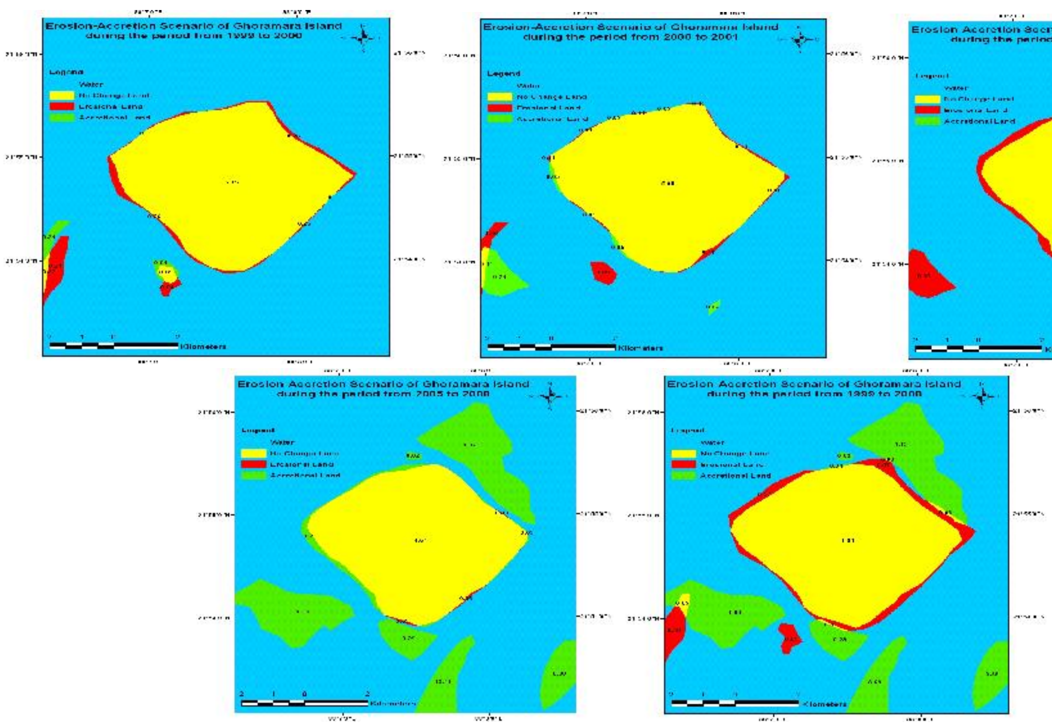

Fig. D : Stable and changed landmass (area in sq km) of Ghoramara Island

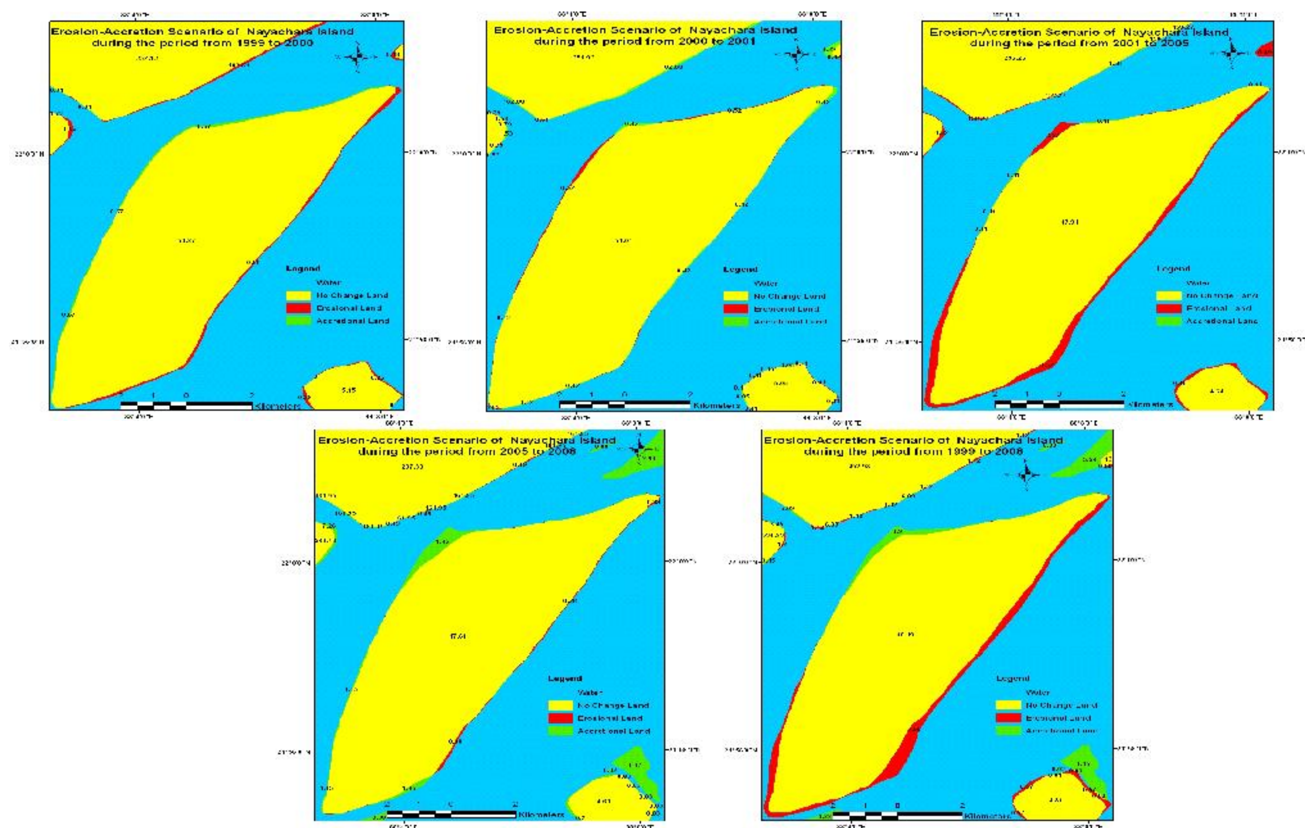

Fig. E : Stable and changed landmass (area in sq km) of Nayachara Island

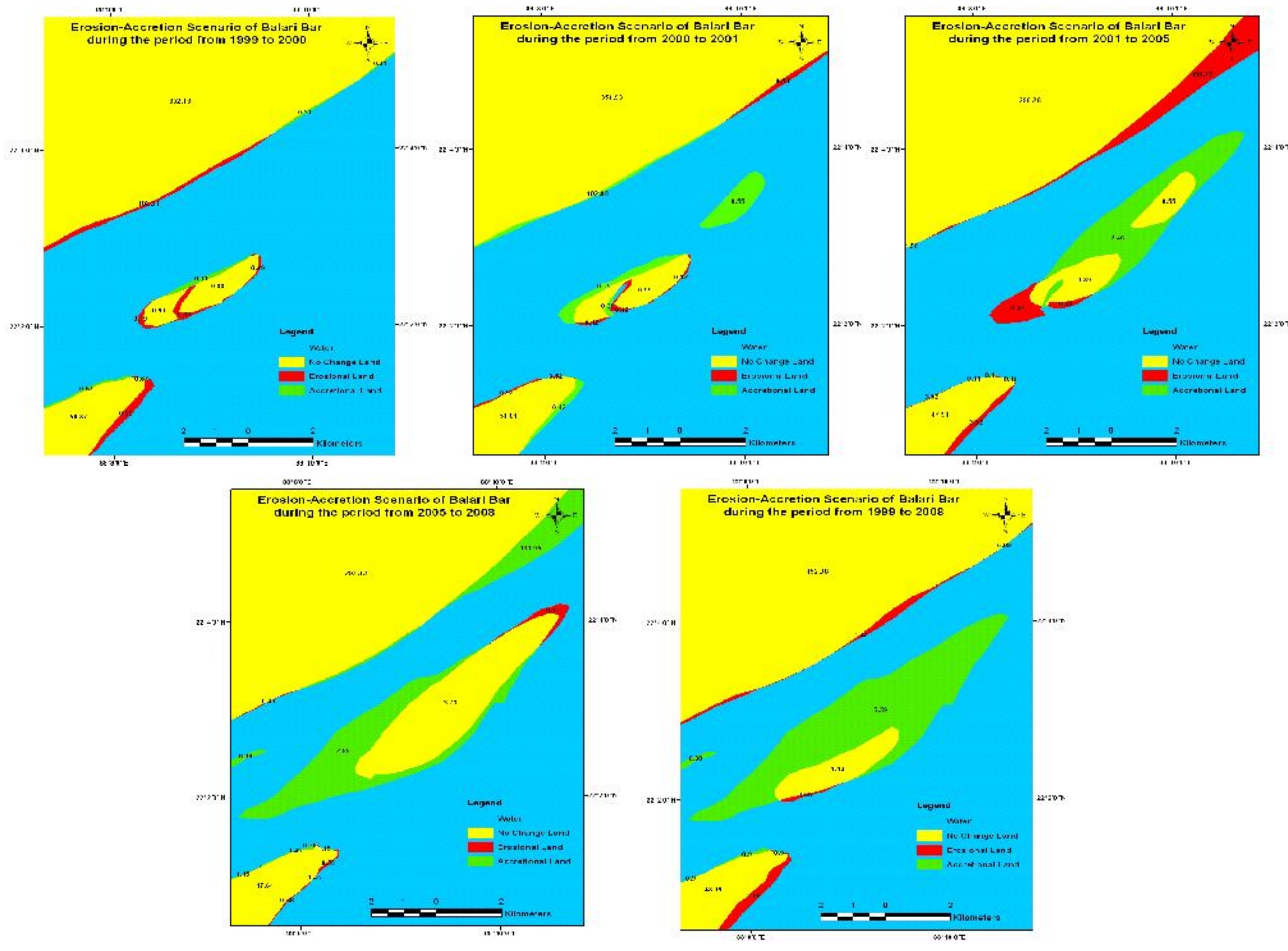

Fig. F : Stable and changed landmass (area in sq km) of Balari Bar

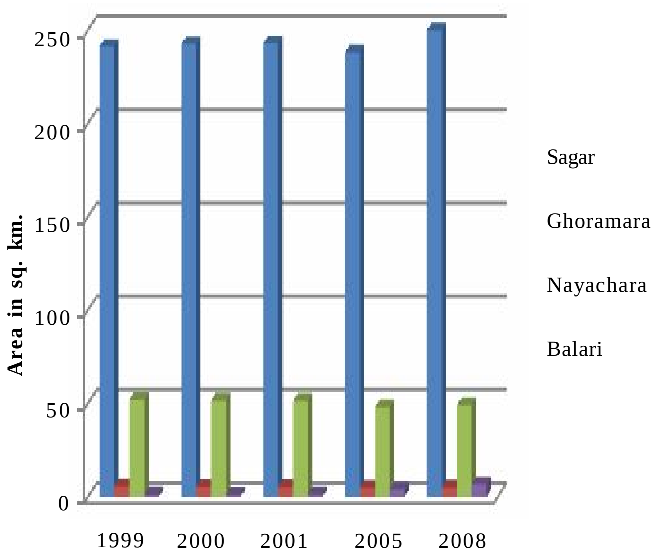

Fig. g : Comparison of change in land area for four Islands of Hugli estuary

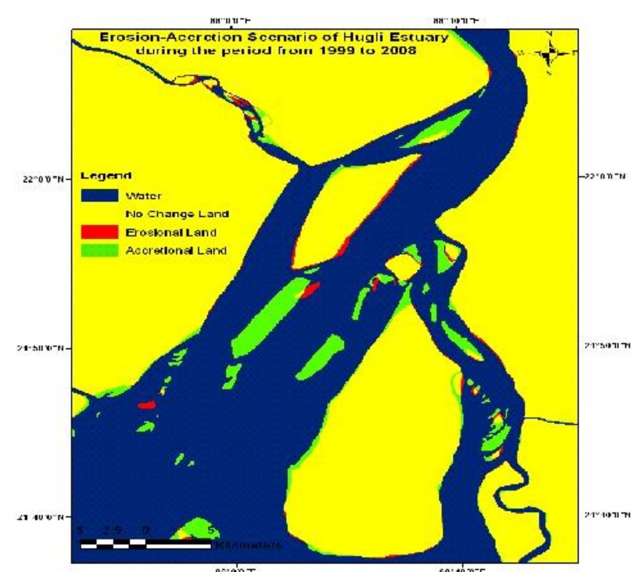

Fig. H : Recent erosion-accretion scenario of Hugli estuary (1999-2008)

RESULTS AND REMONSTRATION

The digital satellite images give an idea about the formation of Jiggerkhali flat, its shape, size and orientation before, during and after the execution of Intensive Maintenance Dredging over the bar. Image interpreted maps clearly explains the transformation of Jiggerkhali flat.

The satellite synchronous tidal information are recorded in Table 1. Sagar, Gangra, Haldia, Balari and Diamond Harbour are the five tidal stations.

The following results have been derived through the analysis of the images :

– The overall health of the estuary was good in 1999. Some deposition had been seen on Haldia channel.
– The Bedford group of Islands are remarkably reduced in size and some of them are totally disappeared.
– Advancement of Bedford channel with nearly complete erosion of Bedford Island is noticeable in 1999.
– A small tail of Nayachara Island was seen in 1999 and since then it has been developed gradually.
– The transverse rotation of the shipping channel from Mud Pt. to Lower Rangafalla channel indicates creation of a slack zone in the tail of Nayachara Island (south eastern part).
– The north-western part of Nayachara Island has been characterized by slight deposition while southern and eastern parts have been eroded during this time period.
– Balari Bar and the tail of Nayachara Island have been developed gradually since 1999.
– Heavy erosional activity has been taken place around Ghoramara Island.
– From 2005 image, erosinal activity around Ghoramara Island and depositional activity near Balari Bar and Sagar Island are clearly visible.
– From 2008 image, it is clear that heavy deposition has been taken place in the north and eastern parts of Sagar Island.
– Area of Balari Bar has been increased during this period.
– Very little amount of accretion has been observed around Ghoramara Island.

Sagar Island during 1999-2008 :

Table 1 shows the change of the entire study area from 1999 to 2008. In 1999 the area of the Sagar Island was almost 241.15 sq km which become 242.51 sq km and 242.98 sq km in 2000 and 2001, respectively. During that time-period the rate of deposition was very low. From the 2005 data the area of Sagar island has been determined as 237.84 sq km which seems that 5.14 sq km area has been eroded in this four years. But it may be considered that this reduction in area is only due to disappearances of the coastal landmass because of high tides at that particular date (Table 1). The 249.87 sq km area of the Island from the 2008 image shows the gradual increase of landmass due to depositional activities. Table 3 depicts the relative comparison between the common

Table 1 : Tidal information synchronous with satellite passes

Date	Satellite data	Time of pass	Tide in metre				
			Sagar	Gangra	Haldia	Balari	D. harbour
28.11.1999	IRS 1C LISS-III	10.30 A.M.	N.A.	2.5	2.27	1.9	1.5
27.03.2000	IRS 1C LISS-III	10.30 A.M.	N.A.	1.5	2.2	2.12	1.65
19.02.2001	IRS 1D LISS-III	10.30 A.M.	3	3.2	3.58	3.65	3.15
20.11.2005	IRS P6 LISS-III	10.30 A.M.	4.1	3.95	3.75	3.68	3.15
28.02.2008	IRS P6 LISS-III	10.30 A.M.	1.93	2.6	2.35	2.66	1.96

Table 2 : Change in land area (sq km) with time for different Islands

Year	Sagar Island	Ghoramara Island	Nayachara Island	Balari bar
1999	241.15	5.42	51.85	1.19
2000	242.51	5.15	51.53	1.10
2001	242.98	5.10	51.43	1.38
2005	237.84	4.64	48.02	3.90
2008	249.87	4.82	49.09	6.72

area and also the area under erosion and deposition during the different successive time-spans. It is very much clear from the table that the overall area under erosion is only 1.16 sq km in comparison to the 9.87 sq km of area under deposition. 240 sq km area was common during this time period.

Ghoramara Island during 1999 -2008 :

From 1999 to 2005 the Ghoramara Island was gradually eroded with an alarming rate. But after 2005 some depositonal land are also formed in the northern and southern direction of Island. But, one thing should be kept in mind that during 2005 to 2008 the water level is decreased from 3.95m to 2.93 m. Hence, it may be considered that some of the extra land may also be found due tidal activity. Table 2 shows the change of the entire study area from 1999 to 2008. In 1999 the area of the Ghoramara Island was almost 5.42 sq km which become 5.15 sq km in 2000. At that time-period the rate of erosion was faster than the later years. From 2000 to 2001 the erosional activity was comparatively lesser and only 0.05 sq km area was reduced from the total landmass. But, after 2001, again the rate of erosion was much higher and area of the island becomes 4.64 sq km in 2005. Lastly, the area was 4.82 sq km in 2008. Table 1 reveals the tidal information synchronous with satellite passes throughout the time-period. These information for Ghoramara Island has been derived from Gangra station which is the nearest tidal station of the Island. In 2005 high tide was recorded 3.95 m. Hence, some land area may be invisible due to the submergence by tidal effect. Table 3 depicts the relative comparison between the common area and also the area under erosion and deposition during the different successive time-spans. It is very much clear from the table that the overall area under deposion is only 0.0088 sq km in comparison to the 0.61 sq km of area under erosion. 4.81 sq km area was common during this period.

Nayachara Island during 1999 -2008 :

From 1999 to 2001 the Nayachara Island was gradually eroded but amount of erosion is quite negligible. It shows a very dynamic and complex hydro-geomorphologic character of the Island (McDowell and O'Connor, 1977). It appears that during post dredging scenario, in absence of any river regulative measure, the area around Nayachara have undergone fast changes due to the imbalance created by the stressed flow and the system as a reaction developed resistive forces enabling the morphological changes occurring in those areas. The above interpretations, analysis and inferences are drawn on the basis of satellite data interpretation. Table 2 shows the change of the entire study area from 1999 to 2008. In 1999 the area of the Nayachara Island was almost 51.85 sq km which become 51.53 sq km and 51.43 sq km in 2000 and 2001, respectively. During

Table 3: Recent erosion-accretion scenario of Islands of Hugli estuary during 1999-2008

Time-period	Sagar Island (Area in sq km)		Ghoramara Island (Area in sq km)		Nayachara Island (Area in sq km)		Balari bar (Area in sq km)	
	Eroded or disappeared	Accreted or appeared	Eroded or disappeared	Accreted or appeared	Eroded or disappeared	Accreted or appeared	Eroded or disappeared	Accreted or appeared
1999-2000	5.15	50.87	0.26	0.0006	0.99	0.67	0.19	0.11
2000-2001	5.05	51.01	0.11	0.0505	0.52	0.42	0.12	0.39
2001-2005	4.64	47.91	0.46	0.0010	3.52	0.11	0.49	3.02
2005-2008	4.61	47.64	0.03	0.2047	0.38	1.45	0.17	2.99
1999-2008	4.81	48.19	0.61	0.0088	3.66	0.90	0.06	5.59

Table 4 : Assessment of morphological changes of Nayachara Island (1999-2008)

Year	Length of Nayachara Island from northern tip in km	Maximum width in km	Width (500 m below the northern tip) in km	Orientation of Nayachara Island (with respect to north) in degree
1999	15.894	4.752	0.905	30.5
2000	15.887	4.798	0.966	30.5
2001	15.849	4.626	0.858	31.0
2005	15.707	4.524	0.765	32.0
2008	15.832	4.723	0.718	32.0

that time-period the rate of erosion was not excessive. From the 2005 data the area of Nayachara Island has been determined as 48.02 sq km which seems that 3.52 sq km area has been eroded in this four years. But it may be considered that this reduction in area is only due to disappearances of the coastal landmass because of high tides at that particular date (Table 1). The 49.09 sq km area of the Island from the 2008 image shows the gradual increase of landmass due to some accretion. Table 3 depicts the relative comparison between the common area and also the area under erosion and accretion during the different successive time-spans. It is very much clear from the table that the overall area under accretion is only 0.90 sq km in comparison to the 3.66 sq km of area under erosion. Almost 48.19 sq km area was common during this entire time period. Table 4 presents the morphological dynamics of Nayachara Island with respect to length, width and orientation from north line. A reduction of 0.062 km (15.832 km from 15.894 km) in length from the northern tip has been noticed in the given years. Along the surface level the reduced maximum width of the island was only 0.032 km (4.752 km - 4.723 km) while at 500 m below the northern tip the estimated width was 0.187 km (0.905km -0.718 km). The result shows that the rate of erosion is much higher in the submerged part of the island. Moreover, there is a slight rotational shifting of 1.5^0 respect to the north line has also been marked in the given time period. These information depict a perfect dynamic morphological nature of the island.

Balari bar during 1999 -2008 :

The images are processed to extract maximum information regarding the (i) growth of the bar, extension of the sand tail both at u/s and l/s of the bar, (ii) adverse growth of western edge of Nayachara (opposite to Haldi river confluence) and (iii) any other erosion and/or deposition in the Haldia-Balari compartment. Between 1999 and 2000 very small deposition has taken place in west-central part of Balari bar and small portion of central and southern part is eroded. From 2000 to 2001 a thin sheet of deposition has been seen in the total western part. A small sand bar is also developed in the North-east side due to accretional activity. Between 2001 and 2005 the southern portion of Balari bar was completely eroded and heavy accretion was seen along the north-east part of the bar and two bars were completely joined. Some changes have been taken place during 2005 and 2008. Erosional activities are seen only along the north-east portion whereas south-western portion were under complete accretion process. The formation of a knuckle in the western edge of Nayachara further restricts the flow through Haldia-Balari region. The region encompassed by lower sand of Balari and G/ wall not conducive to improve flow phenomena. The bed slope seems to be not favourable for inducing flow from 2^{nd} Oil Jetty. Table 2 shows the change of the entire study area from 1999 to 2008. In 1999 the area of the Balari Bar was almost 1.19 sq km which become 1.38 sq km in 2001. At that time-period the rate of deposition was comparatively slow than the later years. But, from 2001 to 2008 a huge deposition has been taken place as the overall area becomes 6.72 sq km. The above qualitative interpretations and analyses are provided on the basis of Software based satellite data processing and calculation. Table 1 reveals the tidal information synchronous with satellite passes throughout the time-period. In 2001 and 2005 high tides ranges between 3.60 and 3.70 m has been recorded. Hence, some land area may be invisible due to the submergence by tidal effect. Table 3 depicts the relative comparison between the common area and also the area under erosion and accretion during the different successive time-spans It is clear from the table that the overall area under erosion is just 0.06 sq km in comparison to the 5.59 sq km of area under accretion.

Conclusion :

While summing up the activities of last 3 years, it is observed from image analyses that the peripheral growth of Nayachara Island between 2005 and 2008 has played a crucial role in deflecting and/or cessation of ebb flow through Lower Rangafalla Crossing. This growth along with the emergence of a sub-merged shoal has straightened the ebb flow through Bedford channel. As a result the bifurcation of flow leading from Sagar face to Bedford and Jellingham channel occurs at a Point much below the tail of Nayachara Island thus, the proposed guide wall with its present alignment has little to do with the deflection of flood flow.

If we compare the two digital satellite images of 1999 and 2008 then the total picture of Hugli estuary would be clearly visible. Here a subset part of whole image is taken for the comparison of these two years. The latitudinal extension of the study area is between 21degree 08 minute North and 22 degree 16 minute North and longitudinal extension is between 87 degree 34 minute East and 88 degree 19 minute East. The total area of the subset image is 7015.77 sq km. The total area of water is 4413.72 sq km. The common land area in the two images is 2464.41 sq km. The area of eroded land is 25.03sq km and the area of deposited land is 112.68 sq km. So accretion is much more dominated than erosion in this area of Hugli Estuary during the period from 1999 to 2008. It appears that during post dredging scenario (IMD) the area around Balari, Rangafalla and Bedford, in absence of any river regulative measure, have undergone fast changes due to the imbalance created by the stressed flow and the system as a reaction developed resistive forces enabling the morphological changes occurring in those areas. The above interpretations, analyses and inferences are drawn on the basis of satellite data interpretation. Apart from detailed Numerical and Hydraulic Model studies, hydrological analyses with detailed hydrographic survey will be required for the formulation of the comprehensive river training scheme (Pritchard, 1952).

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