Process Form Responses of Shoreline Erosion Using Geo-Spatial Techniques: Case Study in Muriganga-Saptamukhi Interfluvium, Sundarban

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Abstract

The numerous tidal river systems have made Sundarban delta one of the most dynamic geomorphic regions of the world. Through time morphological shape and extent of shoreline and river bank configurations have changed considerably through intense erosional and depositional processes by the longshore current and tidal flow pattern in Sundarban. The present study has made an assessment of morpho-dynamic behavior of bank lines for the time-period between 1925-26 and 2014 to identify nature and extent of erosion and deposition of different geomorphic units through consultation and preparation of geo-spatial database comprised of old maps and recent satellite images. Besides, detailed field investigations have also been carried out to understand different processes regarding the bank line changes. Finally different erosion hazard zones have been identified based on the net areal changes.

Keywords: Bank line changes, Erosion hazard zones, Hydro-geomorphic units, Net areal change, Sundarban

Introduction

The Earth's surface is continuously undergoing variety of physical and chemical changes. To understand the nature of these changes, their rates and relationship between form and process is the principal task of process-geomorphology. Coastal geomorphology is an emerging science with multidisciplinary approach mainly incorporates the study of coastal geomorphic environments, estuarine environment, their evolution, nature of neotectonic force acting on them, sediment dispersal, the processes at work on them and rate of changes now taking place. The coastal geomorphology comprised the study of different landforms in time and space. These landforms take their shape depending upon the ongoing coastal processes like erosional and depositional activities. Most of the coastlines owe their basic configuration to tectonic forces, coastal and estuarine hydrodynamic processes and geo-climatic hazards etc. It is noteworthy to mention that, nearly 75% of the world population resides along the coastal region. In this background proper understanding of coastal processes and changing coastal as well as estuarine landforms are necessary. In the last few decades, quantitative analyses on the bank line shift and shoreline configuration has been done by several scientists (Bandyopadhyay and Bandyopadhyay, 1996; Bandyopadhyay *et al.*, 2004; Raju *et al.*, 2010; Rahman, 2012; Chakraborty, 2013; Das *et al.*, 2013). The present work endeavors to establish the dynamic nature of bank line configuration in estuarine belt of Sundarban to identify intensive erosion hazard zones in connection to ongoing processes using multi temporal database and geo-spatial techniques. This type of study can facilitate to build up structural and non-structural

measurement strategies to overcome inconceivable land loss for geomorphologically chronicle areas like the Sundarbans.

Geographical Appraisal of the Study Area

The vast low lying flat deltaic tract of Sundarban has formed in the mouth of the Ganga Brahmaputra. The landform building processes are very active in this deltaic region. The central and northern part of the active deltaic tract of Sundarban has been affected by strong tidal force by tidally active rivers, at the same time the extreme southern part has been significantly affected by long shore current and strong wave dash activities of the Bay of Bengal (Bandyopadhyay and Bandyopadhyay, 1996; Paul, 2002; Das, 2006; Mikhailov and Dotsenko, 2007; Bandyopadhyay, 2007; Purkait, 2009; Chakraborty, 2013). The study area is situated in the western part of Sundarban in between Saptamukhi River in the east and Muriganga River in the west extending from 21° 32' 52" north to 22° 0' 40" north and 88° 7' 7" east to 88° 22' 28" east. Northern boundary has been demarcated based on Dampier–Hodges line which distinguished tidally active Sundarban delta from mature delta in north (Fig. 1). The region has experienced progressive land reclamation processes in last two centuries. At present population growth rate of this region is very fast. Thus, with the increasing population and land reclamation the natural landscape of Sundarban has been converted into human occupied territory (Mukherjee, 2002). The flat sandy coastal land is the main geomorphological characteristic in its southern tract. The central part of the study area is characterized by low lying flat topography with large number of interconnected tidal creeks and mostly lying at 2.8 to 4 meters elevation from mean sea level. Only the northern part is slightly elevated than the rest of the study area and the elevation from mean sea level is 3 to 6 meters on an average. This unique hydro-geomorphic setup makes marginal part of the study area very dynamic through the erosion and depositional processes (Chakraborty, 2013; Das *et al.*, 2013).

Fig.1: Geographical and geomorphological map of the study area.

Data Base and Methodology

The concerned study focuses on the spatio-temporal changes of bank line shifting, extent of erosion and deposition along with erosion hazard zonation in western Sundarban using multi temporal maps and images (Table-1). The changing bank line configuration, extent of erosional and depositional patches have been extracted by imposing sequential digitized layers of successive periods (Bandyopadhyay and Bandyopadhyay, 1996; Bandyopadhyay *et al.*, 2004; Raju *et al.*, 2010; Mukhopadhyay *et al.*, 2011; Rudra, 2012; Chakraborty, 2013; Das *et al.*, 2013; Laha and Bandyopadhyay, 2013 Bandyopadhyay *et al.*, 2014; Ghosh and Mukhopadhyay, 2016). After that, the net areal changes of different geomorphic units have been calculated from the total amount of erosion and deposition (between 1925-26 and 2014) to identify different erosion prone areas. Lastly to establish the adequacy of the present analysis repeated field checks were undertaken.

Table- 1: Materials used for the study.

Maps		Scale		Time period	
Police station maps of Kakdwip and Namkhana (Made and published under the authority of settlement officer Govt. of West Bengal)		1:63,360		1925 - 26	
Survey of India Toposheets(79 c/1, 79c/2, 79c/5, 79c/6)		1:63,360		1942	
Survey of India Toposheets (79 c/1, 79c/2, 79c/5, 79c/6)		1:50,000		1967- 68, 1968-69	
Satellite image					
Image	Date of Acquisition	Path	Row	No. of Bands	Spatial Resolution
IRS P6 LISS IV	18/02/2014	108	57	3	5.8 metres

Hydro-Geomorphic Setup of the Study Area

The whole region can be sub-divided into four geomorphic units based on their diverse morphological setup, major processes and active operating agents (Table -2; Fig.1).

Spatio-temporal Extent of Erosion and Depositional Activities

The entire Sundarban deltaic region is strongly affected by tidal action. The region has two separate entities, the coastal tracts in the extreme southern part of the present study area has been influenced by long shore current, surges and seasonal wind action. The powerful wave generated during the monsoon season intensely affects the coastal dunes, and marginal sea facing embankments. On the other hand, the central and northern parts of the study region have been affected by tidally active rivers. Tidal flow strikes the exposed marginal land and earthen embankment with intense force and makes tremendous damages. The changing morphological

configuration of the marginal parts clearly depicts erosional processes are active along the outer exposed reaches of the estuary and depositional processes are active along the interior and upper reaches of the estuary over time (Fig. 2).

Table-2: Geomorphic divisions of the study area.

Geomorphic units	Relief	Drainage	Active processes	Active geomorphic agents
Active low lying coastal flat	2- 2.6 mts. Flat and gentle sloping towards south	Tidal creeks connected with sea	Erosion, deposition, shore line changes, Sand dune formation, sands ply, salt marsh formation	Tide, wave, long shore current, seasonal wind action
Active low lying tidal flat	2.6-3.8 mts. Flat and gentle Sloping towards marginal parts from inner part	Tidally active rivers and small creeks with dynamic bank line	Erosion, deposition, bank line changes, flood and prolonged water stagnation	Tidal action and surges
Active low lying island	3.9-2 mts. Flat and gentle sloping towards south	Surrounded by large rivers and creeks	Erosion, deposition of Bank line, shifting sand dune , sands ply, salt marsh formation	Tide, wave, surge, seasonal wind action
Active elevated Tidal flat	3- 6 mts. Slightly elevated and gentle sloping towards south	Moderately Stable small tidal creeks	Erosion, deposition, bank line changes	Tidal action and surges

Source: SOI Toposheets 1967 68, 1968 69, IRS P6 LISS IV Image 2014 and field investigation

In the lower and middle reaches of Muriganga estuary, the exposed concave left bank is severely affected by river bank erosional processes. On the other side, the exposed concave right bank of the lower and upper reaches of Saptamukhi river has been intensely affected by tidal thrust whereas large scale deposition took place along the concave right bank of the river Saptamukhi in the middle reaches of the estuary. The meandering outer concave bank line of Pits Creeks, Hatania-Doania creek is frequently affected by erosional processes whereas along the inner bank successive deposition took place (Fig. 3). Through time erosional processes overtake the depositional processes and the gap between erosion and deposition has increased significantly, thus enhancing the net regressive changes.

Different Processes of Erosion

Geomorphic extent of the Sundarban has changed successively over time depending on the intensity of erosion and depositional processes. The exposed marginal banks of the tidally active rivers have been severely affected by erosional processes, whereas sandy coastal beaches in the extreme southern parts of the study area have been severely blown up by the waves and long shore currents. The erosional processes are active in the exposed coastal belts and exposed concave river banks of the estuary, whereas the depositional processes are active in the inner

sheltered reaches of the estuary. Different forms of bank erosion have been given in detail in the Table- 3.

Fig. 2: Spatio-temporal extent of erosion and deposition.

Fig. 3: Different forms of bank erosion (a, lateral erosion, b, under cutting, c, bank scouring, d, translational slide, e, slumping and f, exposed mud sheet in different reaches of estuary).

Table- 3: Different forms of bank erosion in the Muriganga Saptamukhi interfluvium.

Erosional processes			
Process	Forms	Location	Probable factors and agents
Hydraulic action Abrasion Attrition	Bank scouring	Mouth reach of Muriganga river (left bank of Masuni island)	Tidal action, wave dash, exposure, Steep bank slope
	Under cut and subsidence	Meandering concave banks of Pits creek and Hatania-Doania creek in the middle reach of the estuary	Tidal flow direction, channel pattern, Very steep bank slope, sinuous channel pattern, bank composition
	Lateral slide	Middle and upper reaches of Muriganga river	Tidal flow velocity, Steep bank slope, bank composition
	Slumping and Rotational slide	Upper reach of Saptamukhi river, middle and eastern part of Hatania-Doania creek in the middle reach of the estuary	Tidal flow velocity, Steep bank slope, sinuous channel pattern, bank composition
	Translational slide	Lower and upper reach of Saptamukhi river, eastern part of Hatania-Doania creek near the junction with Saptamukhi river in the middle reach of the estuary	Tidal flow velocity, Steep bank slope, bank composition
	Exposed dune and mud sheet	Fedric island, Henry's island Along coastal tracts in extreme south	Exposure, wave action, cyclonic tidal rush, soil texture
	Scoured rill	Coastal belt along the Henry's island in extreme south	Exposure, wave action, cyclonic tidal rush soil texture
	Erosive mud balls	Low lying coastal belt along the Henry's island	Exposure, wave action, cyclone, tidal rush, soil texture

Source: Based on field survey 2013 – 2016

Favourable Factors of Erosion

Geotectonic setup: Due to the tectonic setup the Bengal basin has been tilted towards east. For this reason the Ganga River has changed its course from the historical past. Now the river used to flow in eastward direction. Due to the shifting course of the river Ganga most of the rivers of the Sundarban region in the western part of the Bengal basin have to go through the paucity of fresh water discharge and sedimentation (Bandyopadhyay, 2007). The southern part of the delta is composed with loosely attached Holocene sedimentary strata and subjected gradual subsidence by the auto-compaction processes. The auto-compaction and gradual land subsidence have increased the relative sea level in the estuarine Sundarban region (Nandy and Bandyopadhyay, 2011).

Estuarine exposure: Sundarban is an active low lying area most of the area lies in between 2 to 6 meters elevation. The behead shoreline with funnel shape river mouths sustain more damage because the water is driven into a confined area by advancing tide and storms. Hence

strong tidal thrust makes the marginal part very susceptible to erosion. In the extreme southern parts the low lying sandy coastal belts and exposed islands are severely affected long shore current, tidal surges and cyclones (Paul, 2002; Hazra, *et al.*, 2010).

Tidal flow pattern: The Sundarban is a macro-tidal estuary where tidal range varies from 3m to 5m and may rise up to 8m during normal spring tide. The duration of flood tide is 2 to 3 hours and ebb tide is continued to flow for 8 to 9 hours in 12.4 hours tidal cycle in the Hugli estuary. Thus, the low tidal water cannot properly pass out of the estuary. The average velocity of the flood tide is about 2 to 3 meter/second and ebb tide is < 1 meter/second. Thus, it is found that the out flow continues in the ebb channels when the tide has already begun to move up the flood channels (Paul, 2002; Nandy and Bandyopadhyay, 2011). Thus, the flood tide brings huge sediments towards the estuary and gradually deposited in the shallow river bed disrupting equilibrium condition. Hence to accomplish the equilibrium condition estuary tries to erode the marginal bank and reset the equilibrium.

Channel configuration: Detail observation of bathymetric characters shows that the tidal rivers are characterized with some deep and shallow channels. The high tidal water enters through the shallow water channel and ebb tidal flow passes through the low deep tidal channel. All the deeps narrow elongated channels regulate the activities of erosion and deposition within estuary. The hydrodynamic forces concentrate within these elongated narrow channels at the ebb tide to produce maximum erosion in the estuary banks (Paul, 2002). Distribution of thalweg line and pattern of channel has strong connection with the erosion and depositional extent. The exposed concave banks of Muriganga and Saptamukhi river in their upper- middle and lower reaches are intensely affected by erosional processes whereas the inner concave banks have experienced deposition.

Fluctuation of mean tidal height: The estuarine part of Sundarban is funnel shaped. Hence, land ward increasing pattern of mean tidal ranges is commonly observed in estuarine tracts of Sundarban. Along with this, rapid sedimentation and land subsidence in connection with sediment auto- compaction also triggered the tidal ranges. Landward increasing pattern of tidal level is commonly noticed in Hugli estuary (Bandyopadhyay and Nandi, 2011). The present study attempts to understand long term changes in the mean sea level conditions sourced from the Permanent service for mean sea level (PSMSL) available in revised local reference (RAL) format. The study has decisively used long term annual mean sea level data of two observatories namely; Gangra station (31.4 kilometer from sea) for the periods of 1974 to 2006 and Haldia (43.4 Kilometer from sea) station for the periods of 1971 to 2009. The result shows the gradual land ward increasing trend of mean sea level. Near Gangra it is nearly 0.41 millimeter per year but near Haldia the rate of increase is about 1.33 millimeter per year. Hence the shape of the estuary, sedimentation rate, land subsidence rate are seems to be responsible factors for such trends. The southwest monsoonal season has maximum tidal intensity hence erosional processes are much more active during this season (Hazra *et al.*, 2010).

Cyclonic activities: Sundarban act as a transitional zone between Bay of Bengal and land masses. The cyclone originated over Bay of Bengal moves towards northern direction and directly knocks in this region (Bandyopadhyay, 1997; Hazra, *et al.*, 2010; Danda *et al.*, 2011; Ghosh, 2012). Heavy downpour, strong wind, massive surge collectively massacred this low lying tidal deltaic flat land through havoc bank erosion and prolonged flooding. Most of cyclonic activities are observed during June to October produce rapid bank erosion and

inundates the marginal low lands. Storm surge height often exceeds 3 meters during cyclones cause greater damage in the low-lying islands and coastal belts.

Alignment of embankment and human interruption: Embankment material, lay out plan of construction, width-height ratio are not been well maintained. The Irrigation and water ways department of Government of West Bengal has constructed brick-lined embankment in some selected areas to prevent the erosion. Though in some most eroding stretches of south western coastal part and outer part of low lying island area the high tidal surges and breaking waves often penetrate and remove the cemented layer from the outer section and consequently the entire structure gradually collapses. Tremendous human interferences in the form of vegetation removal from marginal embankment, open pasture on embankment, constructions of houses at the base of embankment, use of embankment for transport collectively put tremendous pressure on embankment (Indian Institute of Technology, Kharagpur, 2006).

Extent of Erosion Hazard in Different Geomorphic Units

It has already been mentioned that the area has publicized negative alteration of aerial units but the magnitudes of erosion vary significantly over space and time. In order to understand the extent of erosion hazard over different geomorphic units the net change of the concerned area has been formulated out from the superimposed layers of different periods (Table-4 and 5; Fig.4). Any negative changes in shoreline and river bank configuration in this context indicate regressive changes of the geomorphic units which resembles the dominance of erosional processes over depositional processes (Jana *et al.*, 2012; Das *et al.*, 2013). Such an outcome illustrate that the active low lying coastal flat are most hazard prone areas due to degree of exposure, relief, geomorphic set up and strong tidal influences. The active low lying tidal flat in the central part of the estuary is less susceptible to erosion as compared to other regions. The erosional processes predominate along the left side of the study area whereas depositional processes are active along the right side of the region and as a result of which net regressive change is quite meager. Active elevated tidal flat in the upper most part of the estuarine interfluvium is experiencing moderate hazard intensity because the western bank of the Muriganga river is very erosion prone due to tidal flow pattern, and bathymetric characteristic (Fig. 4; Table- 6).

Temporal assessment depicts 60% decline of land area in active low lying coastal flat, 21% decline in active low lying tidal flat, 33% reduction of active low lying island between 1925-26 to 1942. However, upper elevated tidal flat has gained 16% land area over the same temporal scale. Between 1942 to 1967 - 69 active low lying coastal flat declined by up to 10%, active low lying tidal flat increased by up to 3%, active low lying island decreased nearly by 33% and elevated tidal flat decreased remarkably by up to 69% from the previous time frame. And, during 1967-69 to 2014 active low lying coastal flat declined by approximately 28%, active low lying tidal flat has declined sharply by around 81%, active low lying island decreased by nearly 33% and elevated tidal flat declined by almost 46%. The temporal fluctuation of areal units can be explained through the dynamic geotectonic setup of the region, changing trend of cyclonic frequencies, fluctuation of mean tide level, shifting of river thalweg lines, changing channel bed configuration, dynamics flow pattern and nature of human interruptions.

Table- 4: Area under erosion and deposition (in sq.km.) in different geomorphic units.

Time/Area (sq.km.)	Active Low Lying Coastal Flat		Active Low Lying Tidal Flat		Active Low Lying Island		Active elevated Tidal Flat	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
1925 26 - 1942	11.68	0.5	6.4	4.3	4	0.6	4.4	7.9
1942 -1967 68, 1968 69	4	2	5.8	5.9	5.1	1	9.9	1.6
1967 68, 1968 69- 2014	5.5	0.1	7	2.9	5	0.5	6.3	2.4

Source: Police station map of Kakdwip and Namkhana 1925-26, 1942, 1967 68, 1968 69 and IRS P6 LISS IV Image 2014

Table - 5: Spatial extent of erosion and deposition over time.

Geomorphic units	1925-26 - 1942		1942 – 1967-68, 1968-69		1967-68, 1968-69 – 2014	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Active low lying coastal flat	Entire southern part	Patches in eastern and western parts	Southern and eastern parts	Mainly along western part	Almost entire shoreline	Some isolated patches in western parts and eastern parts
Active low lying island	Entire southern part	Some patches in north western parts	Entire southern part	Some patches in north western parts	Entire southern part	Some patches in north western and north eastern parts
Active low lying tidal flat	North east, north west and south east	South western part and central part	North east, north west and south east	South western part, eastern part and central part	North east, north west and south east	South western part, eastern part and central part
Active elevated tidal flat	South western part	North western parts	Almost entire western part	Some patches in south western part	Almost entire western part	Some patches in south western parts

Source: Police station map of Kakdwip and Namkhana 1925 26, 1942, 1967 68, 1968 69 and IRS P6 LISS IV Image 2014

Table- 6: Net changes (sq.km.) of the interfluvial area 1925-26 to 2014.

Time /Area in sq.km.	Eroded area (sq.km.)	Deposited area (sq.km.)	Net change (sq.km.)
Active low lying coastal flat	18.71	0.4	-18.31
Active low lying tidal flat	16.14	9.04	-7.1
Active low lying island	10.73	0.9	-9.83
Active elevated tidal flat	19.66	10.33	-9.33

Source: Police station map of Kakdwip and Namkhana 1925-26, 1942, 1967-68, 1968-69 and IRS P6 LISS IV Image 2014

Fig. 4: Spatio temporal extent of erosion and deposition in different geomorphic units (1925 - 26 to 2014) (Left) and extent of erosion hazard in different geomorphic units (1925 - 26 to 2014) (Right)

Concluding Remarks

Shoreline and the river banks are dynamically related over time and space. The erosional processes are active in the exposed outer reaches of the estuary whereas depositional processes are active in inner, protected sheltered reaches. Over time, amount of erosion overtakes deposition as a result total area is in decreasing state. Further, micro-level analysis depicts the outer coastal belt is most erosion prone followed by the exposed low lying island. On the other hand, erosion hazard intensity is quite less in upper and middle reaches of the estuary. Changes in bank line configuration are directly related with tidal flow velocity, flow direction, channel pattern, bathymetric condition of channel, composition of river banks and locational extent of chars.

Through time the area is experiencing regressive changes over time but amount of net areal change vary significantly between different geomorphic units which may have a negative impact on dwellers. So proper knowledge development about the ongoing processes, intense monitoring of the changing behavior of existing processes, structural and non-structural planning and management and integration between local demands and planning bodies are utmost necessary to overcome the challenges like heavy erosion, unscientific land encroachment for the betterment of Sundarban and its dwellers in near future.

Essence of this work lies in the fact that it explores the spatio-temporal extent of bank line alteration, probable factors of bank line changes, spatial extent of bank erosion hazard in a quantitative manner using multi-temporal maps and images. Moreover, this type of study can be carried out for the entire Sundarban region, which would be useful for the creation of more comprehensive coastal erosion hazard risk maps and a better spatial measurement of the risks associated with such natural hazard.

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