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DELINEATION OF MORPHO-STRUCTURAL CHANGES OF SOME SELECTED ISLANDS IN THE GANGA DELTA REGION, WEST BENGAL, INDIA – A SPATIO-TEMPORAL CHANGE DETECTION ANALYSIS USING GIS AND REMOTE SENSING

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ABSTRACT

Ganga delta region, conventionally known as Sundarban in the Hugli estuary is highly dynamic in fluvio-morphological setting where Fluvio-marine dynamics especially erosion-accretion processes are very much active in the evolution and modification of deltaic environment. The area is not only significant for distinctive costal entity but geomorphologically and structurally a noted landscape also. The study area is located in southern coastal part of West Bengal in India. Nayachara, Ghoramara, SagarIsland and New moor islands have been selected for the present study which are not only ecologically, but economically and politically very much significant. Erosional and depositional activities in the region have been assessed by using multi-temporal satellite images and topographical maps with moderate to high resolution from 1951 to 2011. Used Satellite images are Landsat MSS, Landsat TM, Landsat ETM+ and Landsat TM in 1977, 1990, 2000 and 2011 respectively. Topographical maps have been used for geo-referencing of satellite images and extraction of actual area of the selected islands in 1951to 2011. Actual area of islands is calculated from satellite images of 1973, 1990, 2000 and 2011. Spatial change and its rate of the selected islands have been carried out from actual area of different years. It has been estimated that the Hooghly estuary is seemed to be a dynamic zone where the processes of erosion and deposition are very active. So this study supports that this dynamic as well as unstable deltaic environment needs to be monitored because it is an important economic as well as navigational corridor for the Calcutta port and its surrounding regions.

KEYWORDS: Multi-date Image; erosion-accretion processes; Rate of spatial change; Geo- rectified Data; Shore-line change; GCPs and GTV.

INTRODUCTION

Delta is a significant depositional form in the last phase of river flow where usually it finishes its course in the fluvio-marine environment. A delta is also explained as an ensemble of numerous geomorphic features. It is initiated when a flow of water-borne sediments from different rivers, covering a wide region, are carried and finally submitted into a standing body of open water, where the spreading processes are inadequately strong to prevent the building of a marginal sedimentary accumulation. The initial stage of evolution of deltas is the anabranching of the main river channels into distributaries as it approaches the sea or a large water bodies. Actually, besides varied fluvio-marine mechanism, the erosion-accretion processes, individually or jointly play dominant role for the evolution and development of deltaic environment in the coastal seas and oceans. In the studied region at the juxtaposition of the land and sea the active and inactive channels with a large variety of depositional features provide sufficiently large variations in the morphology of deltas in the intermediate and upper zones. Like other regions, the studied deltas also vary in size, shape and orientation in relation to the specific deltaic environment. In terms of dimension these are moderate to small features whose structure, composition, morphology and morphometry are completely different from other fluvial features. Large rivers form extensive and wide drainage areas transport and submit huge sediments and consequently construct moderate to large deltaic areas on the coastline. All over the world especially the deltas of Ganga-Brahmaputra in the active region of the Bay of Bengal are noted for their large size and varied dimension. These are not only significant for costal entity but geomorphologically and structurally a noted landform also. It not only generates and evolves wide areas on the adjacent continental shelves but enclosed by deltaic sediments in and around also *(Evans, 2011).* The observation and analysis of morphology and morphometry of size, orientation, shape and rate of modification of all those deltas are utter necessary in terms of its regional significance especially for preserving mangrove forest for maintaining ecological balance, bio-diversity and finally as biological "hotspot" zone. So, four such significantly marked deltas are selected for detection and analysis for the present purpose of study. Many researchers in India and abroad have carried out *anatomical as well as morphological change detection analysis using satellite images along with field observation*. Morgan (1970) explained that the river regime, coastal structure and processes, interactive behavior of the waves and currents and climatic regime are dominant geomorphic variables which in simple and complex combinations produce a great variety of deltaic morphology. River shifting and study of channel changes have been done in the middle Ganga basin *(Philips et al., 1989)* and western India *(Ramasamy et al., 1991). Nayak and Sahai (1983)* worked on change detection studies in Mahi estuary using Landsat satellite images and *Agarwal and Mitra (1991)* carried out photo geomorphological studies to understand quaternary geology. *Paramanik and Jabbar (1990)* have used the multi-date satellite to monitor coastal zone dynamics in Bangladesh. *Hegde and Reju (2007)* carried out their observation and analysis on coastal vulnerability along Mangalore coast in western India and put some strategies to protect the existing configuration and structure *(Morgan (1970). Coastal erosion and rate of shore line change* is a common phenomenon along the coastal lines all over the world and in India also it has been paid much attention in recent times in terms of global warming and climatic change in India. The present study of change detection and analysis has been carried out by a number of coastal geomorphologists, scientists, engineers and land planners to analyse and interpret the dynamics and hazards of the coastal areas *(Niyogi, 1970; King, 1972; Narayanaswamy and Varadachari, 1978; Anwar et al., 1979; Baba, 1979; Moni, 1980; Komar, 1983; Mallik et al., 1987; Mallik and Rao, 1990).* Southern part of West Bengal is totally encircled by Bay of Bengal and almost 350 km. long and diversified coast line is observed which is globally known as Sundarban Mangrove region or The Ganga delta and covers more than 60% of this coastline. A large portion of the Ganga delta is uninhabited and is now occupied by dense mangrove forest with scattered and linear patches of swampy areas known as *Sundarban* after the tectonically induced river capture of Hooghly resulted from basement faulting in combination with major erratic floods in the region *(Elliot, 1978).* A number of active faults are identified by *Morgan and McIntire (1959)* in Quaternary sediments of the delta region.

METHODOLOGY

In view of the present study, *the main objective of the present study* is to assess the changes, orientation, shape and size of the selected Island and to calculate the rate of change in four selected islands (Sagar, Ghoramara, New moor and Nayachara) which are located in Hooghly estuary of West Bengal using multi-date satellite images and Topographical Maps from 1951 to 2011. These four Islands like *Sagar Island, Ghoramara, New moor and Nayachara* have been selected for present study because of their records of frequent geo-environmental and morphological changes (shape, Size, Orientation and Area). Innumerable Islands are emerged in this region but a few are most significant in relation to the anatomic and geomorphic changes in response to fluvio-marine mechanism. The *topographical map and digital data* have been procured and processed in GIS environment from 1951 to 2011. So, to delineate and assign the spatio-temporal changes of the studied Islands are also significant objective of the study. *Finally,* to assign the final morphological set up and to determine the status of the Islands are to be delineated from the present perspectives.

USED DATA AND METHODOLOGY

Multi-temporal and moderate to high resolution Topographical maps, Images along with tectonic, structural and morphological maps have been used for this particular study. Satellite data are *Landsat MSS, Landsat TM and Landsat ETM+* which are available from *Global Land Cover Facility (GLCF) in National Aeronautics and Space Administration (NASA) and Topographical Maps from Survey of India (SOI).* Topographical Maps and satellite data are *fused, geo-referenced and merged in the proper RS- GIS environment using ERDAS and ARCGIS from where digital data were extracted and finally, base map and other outputs are generated enabled with proper methods of geo-rectification using selected ground control points (GCPs) which are treated as Ground Truth Verification (GTV).*

Technical information of the used data sets is given below (Table 1) which is properly rectified as field of spatio-temporal information and subsequently rate of accuracy has been determined by proper algorithms of accuracy assessment. The chronological information were thus tabulated, arranged and analysed by *qualitative and quantitative assessment processes* to proof the descriptive and inferential extraction for extension and rate of spatio-temporal changes.

TABLE 1: Inputs of technical data: Maps and Images Used

Serial no.	Map/Sensor type	Aquired date	Scale/ resolution
1	Topographical map	1951	Scale: 1cm=250m
2	Landsat MSS	17.01.1973	60m
3	Landsat TM	14.11.1990	30m
4	Landsat ETM+	17.11.2000	30m
5	Landsat TM	08.11.2011	30m

Table-1 is representing the technical information of the used data for the present study which involves the assessment, analysis, and interpretation of spatio-temporal changes of *extension, orientation and configuration of the studied Islands and subsequent output of the rate of change* with the help of *qualitative and quantitative measures* using the data from satellite images and Topographical maps with varied spatio-temporal resolution. Topographical maps have been geographically rectified both by GIS environment and GCPs for getting better accuracy and representation. Satellite images are also geometrically rectified by topographical maps and GCPs for better accuracy. Radiometric and atmospheric corrections are also applied to minimize the error, if any, on geometrically rectified images. Thus, corrected images and maps are used to extract the area of islands by digital Image Processing method (in RS environment) of different years. Erosion and deposition rate have been calculated from the extracted areas of the islands. ***Finally,*** change detection analysis has been carried out to assign the erosion -accretion status of the islands (Figure 1).

STUDY AREA

The study area has been selected in the southern part of West Bengal which is popularly known as active delta region of Ganga-Brahamaputra River. It is located in the Southern part of south 24 Parganas district in West Bengal, India. Along with anabranching and anastomosing pattern of active and inactive channels, natural levees, crevasse splays, Chars, mid-channel bars, Shoals, point bars, swamps, mud ridges, strandlines etc. are common forms in the active delta region of Sundarban. But among all those diversified features very small to big Islands are also very common in this region. Above all I have selected four big Islands are Sagar Island, Ghoramara, New moor and Nayachara Islands which are both ecologically and economically significant and have better prospect for the development of this unstable region. Geographically those are delimited by 21º29´4´´ to 22º01´45´´ N and 88º01´28´´ to 88º13´33´´E. latitude and longitude respectively. Total area recorded in the year of 1951 was 393.90 sq km (only for selected deltas, 1951). Mangroves and swampy vegetation are the noticeable coastal vegetation of the areas.

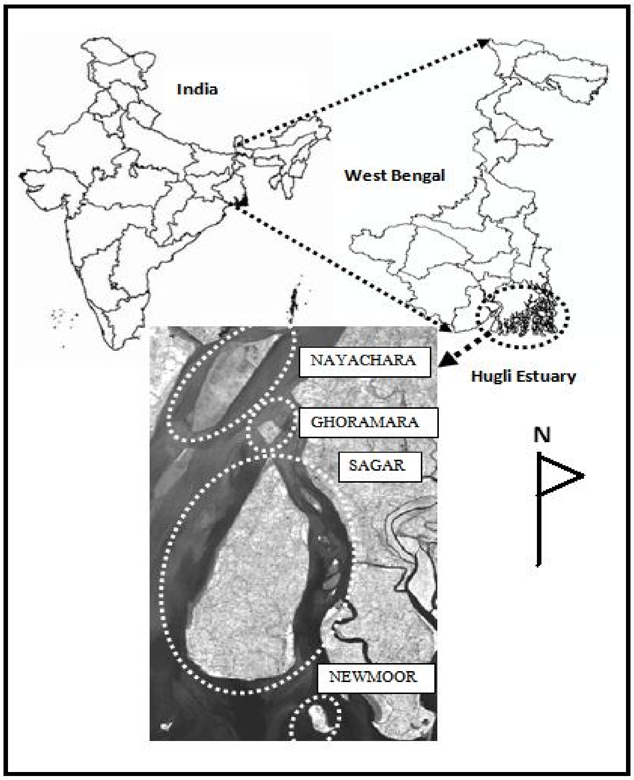


FIGURE 01 - Location of the Study Area

Selected islands are sequentially situated along north to south direction through Nayachara, Ghoramara, Sagar and New moor. Sagar Island is the biggest among them which is covering 285.40 sq.km areas in 1951. Sagar Island is famous since long and though Ghoramara, New moor and Naya char are recent (comparatively) addition but these have got much attention in terms of ecological, environmental, economical and finally have got much political attention in various aspects in this region. So, in this regard these four islands are specially selected for change detection analysis to fulfill the objectives of the recent research.

RESULTS & DISCUSSION

After careful observation, extraction and analysis the changes in spatial and temporal dimension of studied Islands have been examined and resultant output and presentation have been tendered, calculated and analysed with respect to the present objectives of the study. Spatial changes have been interpreted in chronological order from 1951 to 2011 and results are recorded for sequential and comparative analysis of the changing orientation and configuration of the studied Islands. Finally, the rate of changes and their comparative features are explained and highlighted for getting inferences of the respective study. The extractions of spatio-temporal changes are tabulated in the following table.

TABLE: 02 - Spatial change in sq.km. (Coloured are maximum area registered)

Year	Nayachar	Ghoramara	Sagar Island	New Moor
1951	30.16	**38.23**	**285.40**	**40.11**
1973	27.43	13.41	244.00	9.55
1990	42.11	6.67	236.95	7.10
2000	**53.74**	5.52	247.47	7.93
2011	45.86	4.37	239.23	4.93

TABLE 3: Statistics of Accretion (+) and Erosion (--) status of the studied Islands (Base Year 1951)

Islands - Total Area in SQ. KM. Base Year - 1951	LAND AREA LOSS (+) / GAIN (--) OF THE RESPECTIVE ISLANDS								
	Average annual rate of change	NAYACHAR		GHORAMARA		SAGAR Island		NEW MOOR	
		(+)	(--)	(+)	(--)	(+)	(--)	(+)	(--)
Nayachar - 30.16	1951 - '73	00	2.73	00	24.82	00	41.40	00	30.56
Ghoramara - 38.23	1973 - '90	14.68	00	00	6.74	00	7.05	00	2.45
Sagar Is.- 285.40	1990 - 2000	11.63	00	00	1.15	10.52	00	0.83	00
New Moor - 40.11	2000 - '11	00	8.00	00	1.15	00	8.24	00	3.00
Statistics of Loss and Gain of the Respective Island		(+) 26.31 (--) 10.73		(+) 00.00 (--) 33.86		(+)10.52 (--)56.39		(+) 0.83 (--) 36.01	

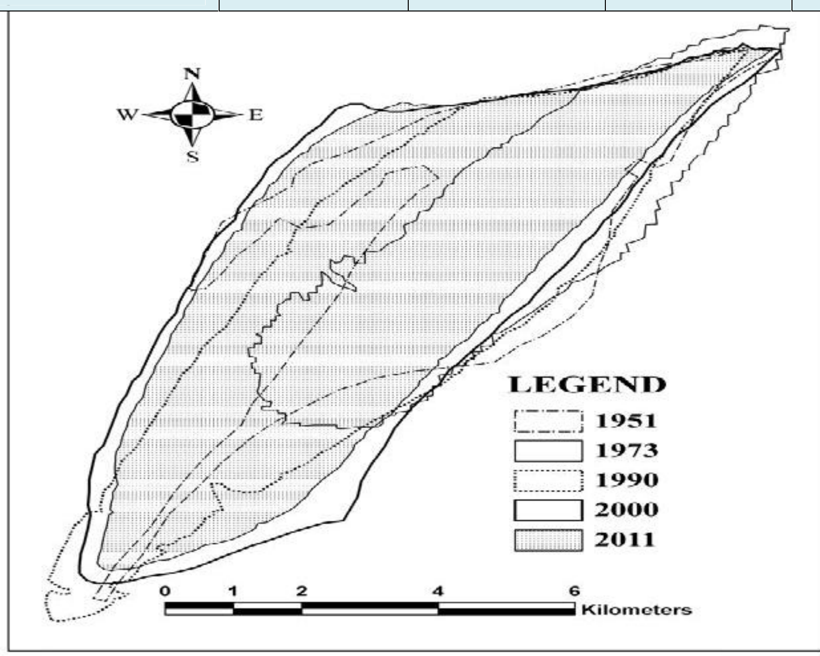


Fig.- SPATIO-TEMPORAL CHANGE OF NAYACHAR ISLAND

IGURE 02 - Existing Configuration of Nayachar Island (2011)

a) Spatial change (Loss and Gain) - Orientation and Direction

From the above table ***(Table No -2)*** the temporal change of areas of four Islands is depicted and a clear picture is reveled about the gain and loss of the Island areas in view of temporal perspective (Table -03).

i) ***Area of Nayachara Island*** in 1951, 1973, 1990, 2000 and 2011 has been 30.16 km², 27.43 km², 42.11 km², 53.74 km² and 45.86 km² respectively. The area was reduced by 2.73 km² during 1951 to 1973. The area had been mostly eroded in western part and partly eroded in southern part and eastern part of the island while some had deposition in the eastern, north-eastern, northern, south-eastern and south-western part of the island. The area of Nayachara Island has increased around 14.66 km² from 1973 to 1990. In the north-eastern part, the area has decreased while southern, south-western and western parts have increased. During 1990 to 2000, the area was increased around 11.63 km² in the direction of western, south-western and south-eastern part while some area has decreased in southern and eastern part of the island. The area has decreased by 7.88 km² during 2000 to 2011 from all directions of island except the northern part (Figure 2).

ii) ***In 1951, 1973, 1990, 2000 and 2011, the area of Ghoramara Island*** has been 38.23 km², 13.41 km², 6.67 km², 5.52 km² and 4.37 km² respectively. Area has decreased from 1951 to 2011 (1951 to 1973, 1973 to 1990, 1990 to 2000 and 2000 to 2011). In 1951, the island was identified in three parts from north to south direction. Larger part was the northern part and smaller was the southern part. Three parts of the island were there in 1951 and 1973 and last part (southern) was completely eroded in 1990 and in 2000 and 2011, only northern part remains. The area has decreased during 1951 to 1973, 1973 to 1990, 1990 to 2000 and 2000 to 2011 and the decrease is by 24.82 km², 6.74 km², 1.15 km² and 1.15 km² respectively. In the island, deposition was not there but erosion was dominated in all directions from 1951 to 2011 **(**Figure 3).

iii) ***Area of Sagar Island in 1951, 1973, 1990, 2000 and 2011*** were 285.40 km², 244 km², 236.95 km², 247.47 km² and 239.23 km² respectively. During 1951 to 1973, area was decreased to a great extent which was 41.40 km² and the erosion is found in all direction of the island. There were few changes that have occurred in between 1973 to 1990, 1990 to 2000 and 2000 to 2011. In between 1973 to 1990 and 2000 to 2011, area of the island has increased around 7.02 km² and 8.24 km² correspondingly while the area has decreased around 10.52 km² from 1990 to 2000. **(**Figure-4)

iv) ***In 1951, 1973, 1990, 2000 and 2011, the area of the New moor Island*** was 40.11 km², 9.55 km², 7.10 km², 7.93 km² and 4.93 km² respectively. During 1951 to 1973, rate of reduction was highest, which was around 30.59 km². In the southern part, erosion was dominated while in other parts it was less except for the northern part. Area has decreased around 2.45 km² and 3 km² during 1973 to 1990 and 2000 to 2011 respectively and the area has increased by 0.84 km² during 1990 to 2000. In between 1973 to 2000, some part is eroded in northern, western and southern part of the island while some area has shown deposition in the north-eastern and south-eastern part. In north-eastern and south-eastern parts, some area has increased while some other area has shown erosion in the southern part during 1990 to 2000. During 2000 to 2011, area has eroded from all sides except the south-eastern and north-eastern parts while some area has shown deposition in the south-eastern part of the island (Figure 5). Figure-6 explains the spatio-temporal change in the island that recorded from 1951 to 2011 from various evidences.

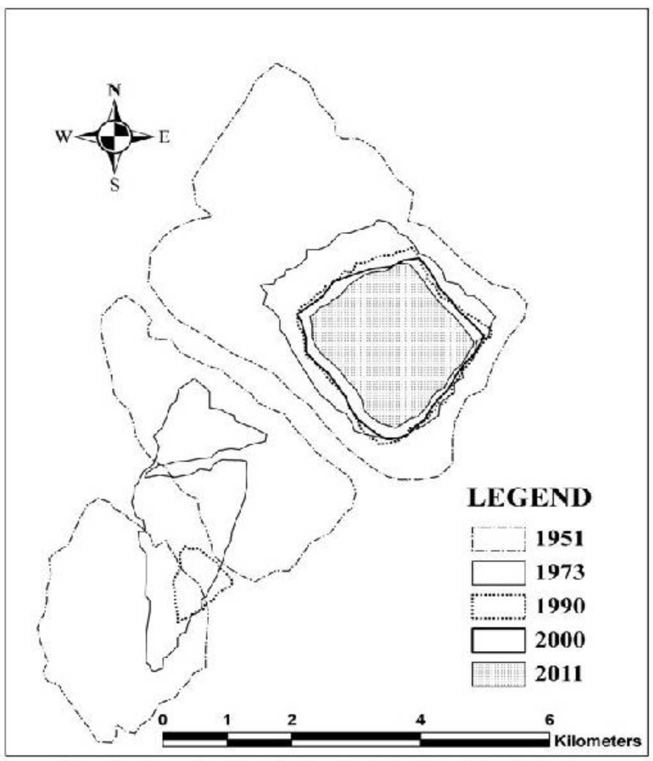


Fig. SPATIO-TEMPORAL CHANGE OF GHORAMARA ISLAND

FIGURE-03- Existing Status of Ghoramara Island (2011)

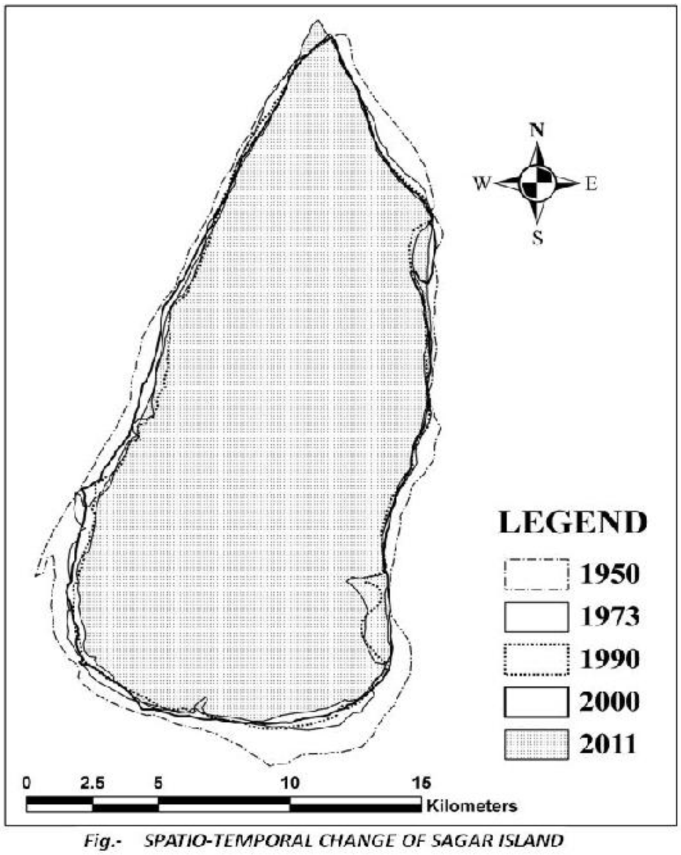


FIGURE 04- Existing Configuration of Sagar Island (2011)

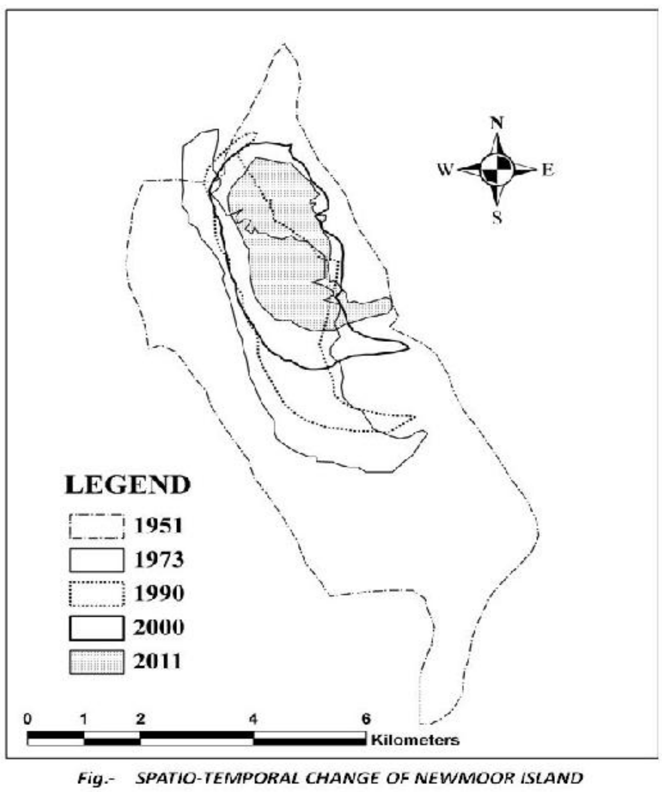


FIGURE 05- Existing Configuration of New Moor Island (2011)

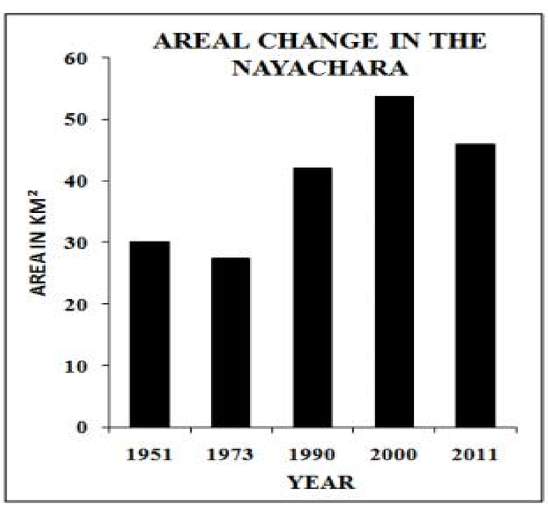
After careful tuning of the above results of spatio-temporal changes some *distinguishing facts are revealed in relation to extension, trend, direction and forms of changes*. These are as follows:

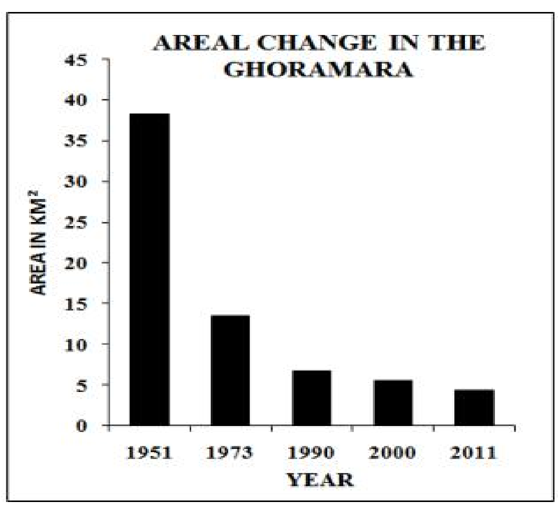
i) The four islands are almost newly formed in terms of geological age. In 1951 the Nayachar Island covered an area of 30.16 sq. km. Up to 2011 it has been observed that except 1973 the deposition dominates and in the year of 2000 maximum area are recorded (536.74 sq. km.). But it has almost stable condition in comparison to other Islands

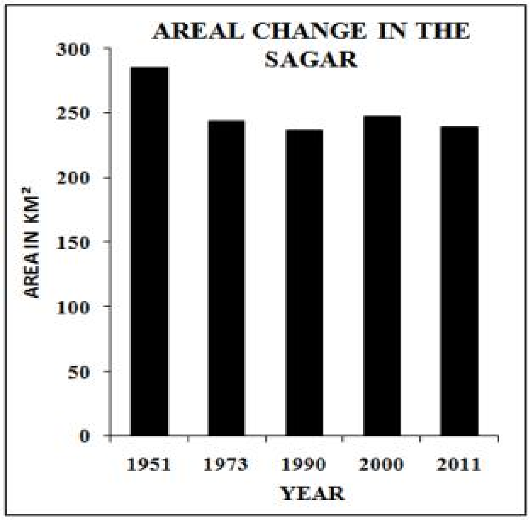
TABLE 04 - Spatio-Temporal change statistics and their comparative viability status

		NAME OF THE ISLANDS			
Year	**span**	**Nayachar**	**Ghoramara**	**Sagar Island**	**New Moor**
1951	**Base**	00.00	00.00	00.00	00.00
1973	22	-0.124 **--9.05%**	-1.128 **--64.92%**	-1.882 **--14.51%**	-1.389 **--76.19%**
1990	17	+0.864 **+53.52%**	-0.396 **--50.26%**	-0.415 **--2.89%**	-0.144 **--25.65%**
2000	10	+1.160 **+27.62%**	-0.115 **--17.24%**	+1.052 **+4.44%**	+0.083 **+11.69%**
2011	11	-0.716 **--14.66%**	-0.105 **--20.83%**	-0.749 **--3.33%**	-0.273 **--37.83%**
Total % Changes		81.14(+) 23.71(-)	00.00(+) 153.25(-)	4.44(+) 20.73(-)	11.69(+) 139.87(-)
% Deviation		***(+)57.43%***	***(-)153.25%***	***(-)16.29)***	***(-)128.18%***
Rank Status		(01)	(04)	(02)	(03)
Viability Status		***Good***	***Vulnerable***	***Moderate***	***Risky***

Spatio-Temporal Statistics of change in studied Islands and Their Viability Status







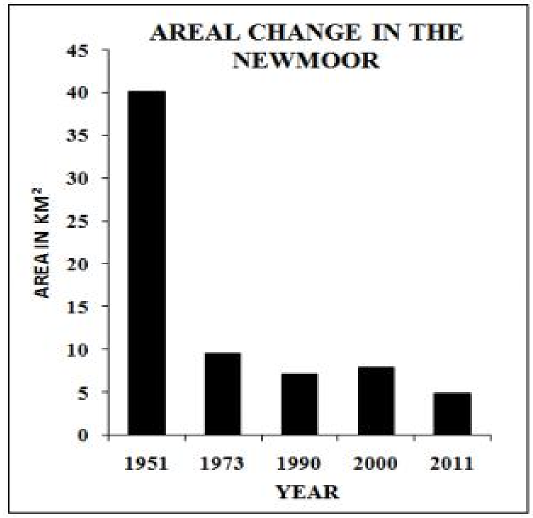


FIGURE 06 - Spatio-Temporal trend of change of areas of studied Islands

ii) The most noticeable fact is that except Nayachar Island all the three islands recorded erosional dominancy and as a result the total areas of all those three islands are decreased. So, recording maximum areas in the year of 1951. In relation to erosion-accretion processes only Nayachar Island reveal slow rate of erosion and higher rate of deposition, but in other cases the rate of erosion is very high and highly variable rate of erosion in distinguishing the islands much risky and vulnerable in comparison to Nayachar island.

iii) Among the four islands the area of Sagar Island is greater and the rate of erosion is also not so noticeable, but in case of Ghoramara and New Moor the rate of erosion is much exceeding in relation to the base year (1951). So, Sagar Island and Nayachar have comparatively better prospect in comparison to other two islands, where erosion is capturing a lot of land almost every year.

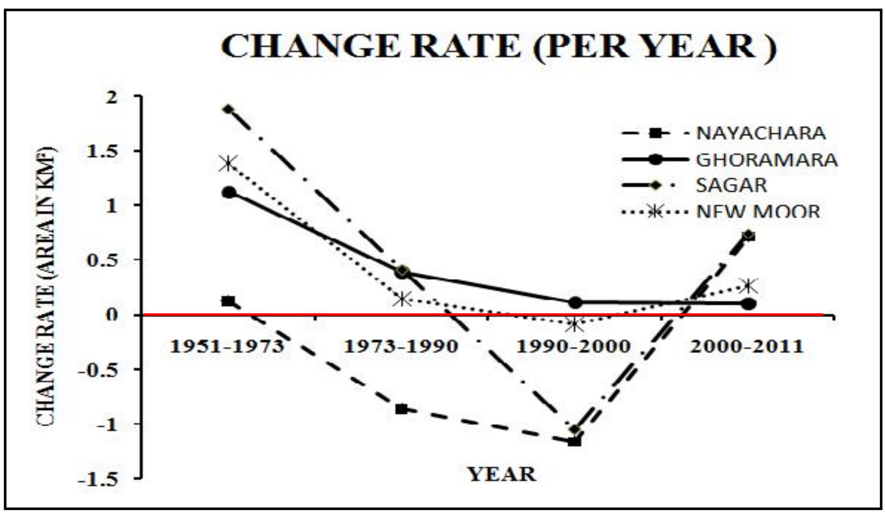


FIGURE 07- Comparative analysis of changing rate of Loss and Gain of areas

b) Rate of change of four Islands

Consecutive and average annual rate of spatio-temporal change of areas of studied islands also reveal some interesting facts in relation to fluvio-marine mechanism of the delta dynamics of the studied area. Rate of change of area has been calculated in km per year. The extracted results of area gains or losses of the respective islands have been calculated and subsequently represented in the table no (s) 02, 03, and 04 and their comparative analysis in terms of their correlation and association are also depicted in the respective diagrams *(Fig - 07).*

a) ***In Nayachara Island***, erosional rate was 0.12 km² and 0.72 km² during 1951 to 1973 and 2000 to 2011 respectively and depositional rate was 0.86 km² and 1.16 km² during 1973 to 1990 and 1990 to 2000 respectively.

b)Erosional rate of the *Ghoramara Island* was 1.12 km², 0.40 km², 0.11 km² and 0.10 during 1951 to 1973, 1973 to 1990, 1990 to 2000 and 2000 to 2011 respectively. So, the rate of erosion is increasing at accelerating rate.

c) ***In Sagar Island***, erosional rate was 1.88 km², 0.41 km² and 0.75 km² during 1951 to 1973, 1973 to 1990 and 2000 to 2011 correspondingly and depositional rate was 1.05 km² during 1990 to 2000. So, in recent time some amount areas have been added.

d) ***Erosional rate of New moor Island*** was 1.39 km², 0.14 km² and 0.27 km² during 1951 to 1973, 1973 to 1990 and

2000 to 2011 correspondingly while depositional rate was 0.08 km² during 1990 to 2000. This island has much fictitious rate of change. Erosion is primarily dominating and the fluvio-marine processes are more active here.

CONCLUSION

The Hooghly estuary is seemed to be a dynamic zone where the processes of erosion and deposition are very active and till recent several interesting additions and subtractions of land parcels are recording. In relation to foregoing results and discussion from the qualitative and quantitative information the four selected islands revealing marked spatial changes by which orientation and directions of islands are also modified and re-oriented. The multi-temporal satellite images and topographical maps have been used to delineate the actual areas of the islands and consequent change detection of the land (respective gain or loss) starting from 1951 the temporal scenario of 1973, 1990, 2000 and 2011 with field verification have also observed and represented for getting inferences of the study. So this study supports that this dynamic deltaic environment needs to be monitored regularly because it offers important navigational corridor for the Calcutta and adjacent ports which is mostly responsible for local as well as regional development of the area.

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