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The evolution of Balari Bar in the Hugli Estuary, West Bengal, India, and its impact on navigation

Aparajita Sen* & Sunando Bandyopadhyay **
Department of Geography, University of Calcutta, Kolkata 700019, India
[E.Mail: *aparajita72@gmail.com **sunando@live.com]

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Systematic study of charts, maps and satellite images pertaining to 1967-68, 1975, 1992, 1997, 2000, 2003, 2006, 2009 and 2012, indicate that the Balari Bar steadily increased, choking up the northern portion of the Haldia Channel, on the west of the Hugli Estuary. Its rapid growth, from 0.29 km^2 in 1997 to 3.83 km^2 in 2012, started to threaten the Haldia Dock Complex (HDC). Eight superimposed profiles across the 15 km Balari Reach of the estuary show gradual deterioration of the western Haldia Channel and the improvement of the eastern Rangafalla Channel resulting in the concentration of the tidal flows in the latter. The decrease in the overall capacity of the reach has been 8.13% from 2000 to 2012. The result of this is reflected on the performance of the HDC as some of its share of cargo is diverted to the other sea ports in the vicinity.

[**Keywords***:* Estuary, Hugli, Balari, Haldia]

Introduction

The Bhagirathi–Hugli is the westernmost distributary of the Ganga delta (Fig.1). In the historical times there has been a consistent eastward shift of the off-take points of the Bhagirathi–Hugli.[1] The discharge from the Ganga has also dwindled over the years. Between 1914 and 1970, the maximum discharge through the Bhagirathi at Jangipur, close to its off-take, reduced gradually from 3,022 to 1,306 cumecs with extremely low dry-season discharge.[2] This meagre flow resulted in rapid siltation in the river bed and the crucial lower reach of the river from Cossipore to Hugli Point got choked up by several bars which restricted the movement of the ships to and from the Kolkata Dock System (KDS). In 1977, the total volume of bank erosion along the Bhagirathi was 30.36×10^6 m^3.[2] It was estimated that about 220 hectares of land is lost every year along the banks of the Bhagirathi–Hugli.[3] Thus a large volume of sediment started to get added to the Bhagirathi–Hugli channel, which is transported to the estuarine reach south of Hugli Point.

The Hugli is a flood-dominated macrotidal estuary with the tidal range varying from 4.3 at the mouth to 4.9 m at Haldia and 5 m at Diamond Harbour, situated 43 km and 70 km upstream. At its mouth, the maximum flood and ebb discharges of the estuary is estimated at 2.6×10^5 and 1.1×10^5 cumecs respectively.[4] The duration of flood tide is about 3 hours in a 12.4 hour tidal cycle, setting up flood velocities in the range of 2–3 m s^{-1}, compared to ebb velocities of <1 m s^{-1}.[5] This results in a net landward movement of sediments due to the time-velocity asymmetry in tidal propagation, making it a sediment sink.[6] It is estimated that in the upper section of the Balari Reach, 51 km from the mouth of the estuary, maximum flood and ebb discharges amount to 6.7×10^4 and 3.7×10^4 cumecs respectively,[7] resulting in 2.5-times higher bedload transport during the floods compared to the ebbs.[8] These features of the Hugli are common to many macrotidal estuaries of the world.[9] During the 20th Century, the Hugli gradually became incapable in accommodating the large ocean liners. The percentage of the total volume of cargo handled by the KDS fell from 49.5% of the India's total in 1928-29 to only 10.7% in 1970-71.[10,11]

Although the Hugli estuary is primarily a sediment sink, active reworking of the deposited material and consequent shifting shoals and bars occurred all through its recorded history.[12,13,14,15] The Jiggerkhali Flat and the Balari Bar was ignored while the plans were made for the construction of the Haldia Dock Complex (HDC) on the western bank of the Hugli as it was thought that these could be easily tackled by some localised dredging.[16] The evolutionary history of the estuarine islands of the Hugli were studied by Chakrabarti, [17] Kumar *et al.*,[18] Prithviraj *et al.*,[19] Bandyopadhyay, [14] Bandyopadhyay *et al.*,[20] and

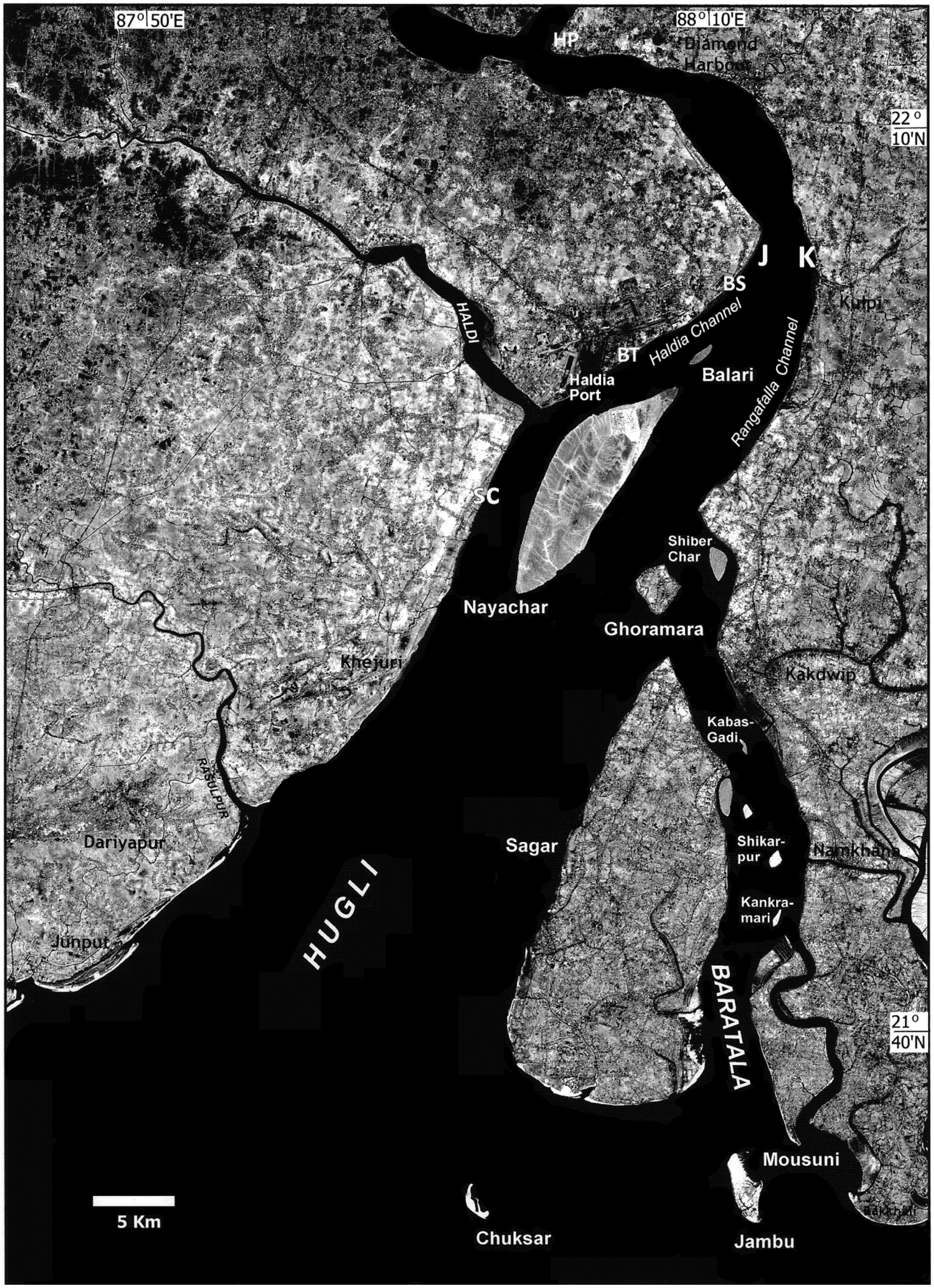

Fig. 1 — The location of the Balari Reach and Balari Island within the Hugli Estuary (HP: Hugli Point, J: Jiggerkhali Flat, K: Kantaberia, BS: Balari Semaphore, BT: Balari Tower and SC: Sondia Column). *Source*: IRS-1D LISS-3 Band-3 (Near Infra-red) image of 25 January, 2001.

Ghosh *et al.*[21] Though the Hugli Estuary is one of the most extensively studied estuaries in India, data related to discharge and bathymetric characteristics are treated as classified. The unpublished reports of the Hydraulic Study Department of the Kolkata Port Trust (KoPT) are the only documentation of the reach under review. Some related works on the bathymetry of the Hugli estuary as a whole include studies by Roy,[13] Hiranandani & Ghotankar,[14] and Banerjee *et al.*[16]

The present article envisages firstly to find out the sequential growth of the Balari Island from 1997 to 2012, and secondly to trace the channel condition of the Balari Reach extending from Balari Semaphore to Balari Tower between 1967 and 2012. This would give a clear picture of the evolution of the Balari Bar and changes in the Haldia and the Rangafalla Channels over a period of five decades.

Materials and Methods

Survey charts of the Hugli, used for this study, were prepared by the River Survey Department of KoPT (Table 1). They give the depth of the estuary in metres (z) at various points (x,y) of the channel, with reference to the Chart Datum, at 3.23 m below mean sea level.[22] The charts of the years 1967, 1975, and 1992 were produced at 1:100,000 (1 cm to 1 km) with limited cross-sectional data shown by the four red lines in the index map of Fig. 2 (designated CS-1 through CS-4); whereas the survey charts of the years 2000, 2003, 2006 2009 and 2012 were represented at 1:25,000 (1 cm to 4 km), from which 23 cross sections could be extracted, which are represented in blue and red lines in Fig. 2. The charts were georeferenced using Geomatica v.2012 software, and point vector layers, depicting sounding positions pertaining to each of the eight survey years, were created. In the attribute table of the vector layers, depths (z) and co-ordinates (x, y) were added from the survey charts and exported to MS Excel v.2010. Depth of each point was adjusted by adding 3.23 m to correspond them to the mean sea level. The adjusted depth was then used to construct bank-to-bank cross profiles of the river at four locations (CS-1, CS-2, CS-3 and CS-4) in the Balari Reach reach for all the years mentioned above. Profiles constructed for the eight survey years were superimposed to show the changes in the shape of the channel.

To study the capacity (volume in cubic metres) of the Balari Reach, the 1:25,000 charts of the survey years 2000, 2003, 2006, 2009 and 2012 were used. 23 line vector layers were created to demarcate cross sections, orthogonal to the estuary, from which, point vector layers — representing 1,405 depth positions — were derived for each of the five survey years. These were used for calculation of capacity.

Subsequently, nine satellite images of similar tidal levels, corresponding to the chart survey years, were obtained for 1997, 2001, 2003, 2006, 2009 and 2012 (Table 2). These were utilised to study the supratidal change in the configuration of the Balari Bar. Each of the nine images were individually georeferenced and, for the years 1997, 2001 and 2003, merged (pansharpened) to enhance resolution. Finally, changes in the supratidal area of the Balari Bar in different years were extracted by digitisation.

Results and Discussion

The superimposed depth profiles CS-1 through CS-4 give a clear picture of the gradual choking up of the Haldia Channel, reduction of the thalweg and development of the Balari Bar (Fig. 2). Profile CS-1 shows a gradual decrease in the thalweg of the Haldia Channel (near the western bank) and increase in the thalweg of the Rangafalla Channel (close to the eastern bank). Further south, the sections CS-2, CS-3 and CS-4 indicate the growth of the bar with elevations above mean sea level at some locations, connoting that the bar has developed into an island. On the eastern side, the thalweg deepening persists along the Rangafalla Channel.

Table 1 — Kolkata Port Trust survey charts used in the study

Name of Chart	Year / Month of Survey	Scale
River Hugli: Bansbaria to Sandheads	1967	1:100,000
	1975	
	1992	
River Hugli: Balari Semaphore to Balari Tower	2000, Nov	1:25,000
	2003, Aug–Sept	
	2006, Sept–Oct	
	2009, Aug–Sept	
	2012, April–May	

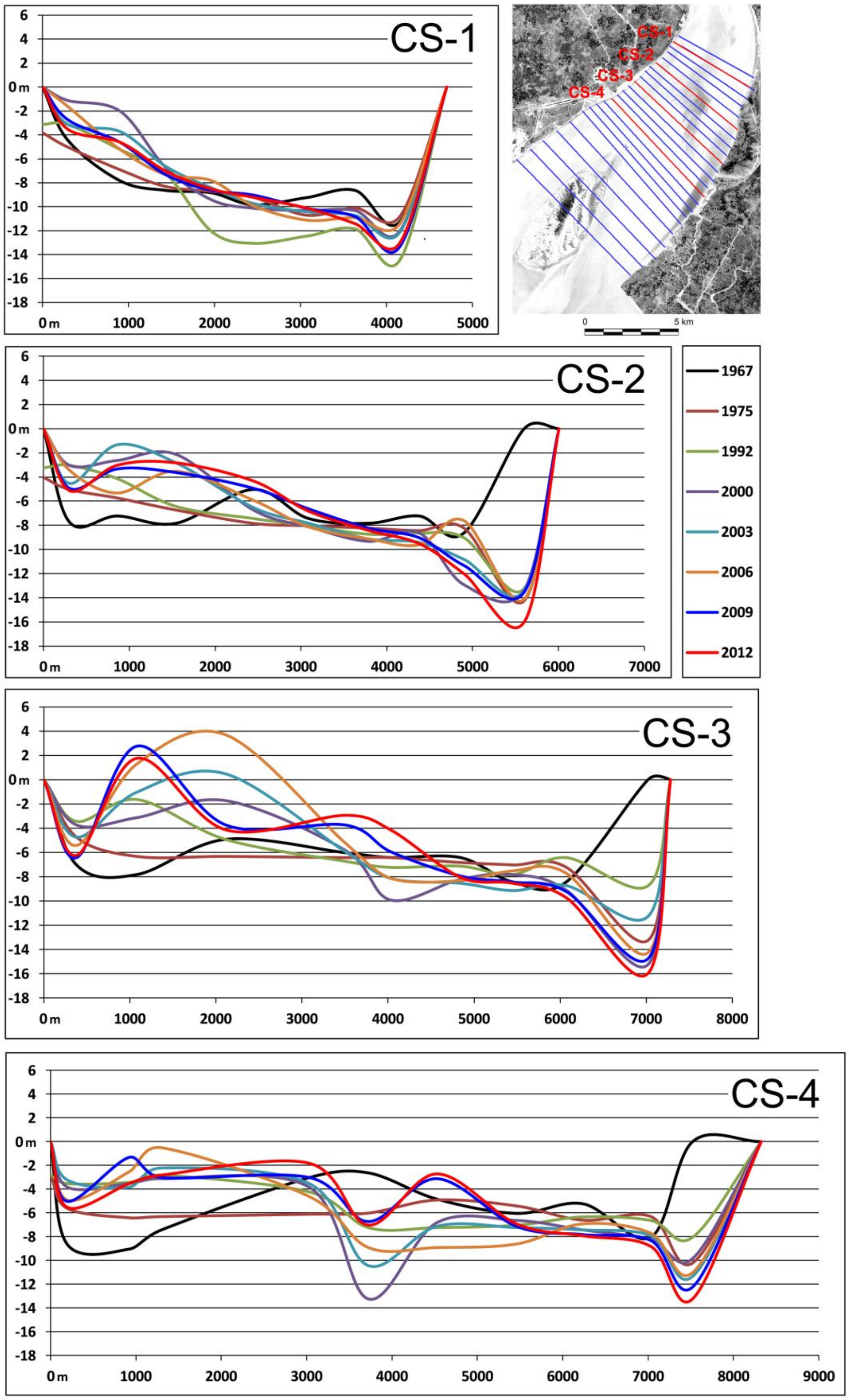

Fig. 2 — Hydrographic profiles along four sections of the Balari reach, Hugli estuary: 1967–2012. The positions of the profile lines are indicated in the inset map at the right upper corner. The Haldia and the Rangafalla navigational channels skirt the western and eastern banks of the estuary respectively. *Source*: see Table 1 for details.

Table 2 — Satellite images used in the study

Satellite	Sensor	Path	Row	Quadrate	SAT [1]	Date of Pass [2]	Resolution	Remarks
IRS 1C	LISS-3	108	057	—	—	1997-02-23	23.5 m	Merged data
	Pan	108	057	C	—	1997-02-23	5.6 m	
IRS 1D	LISS-3	108	056	—	70%	2001-01-25	23.5 m	Merged data
	Pan	108	057	B	—	2000-12-31	5.6 m	
IRS Resourcesat-1	LISS-3	108	056	—	50%	2003-12-25	23.5 m	Merged data
	LISS-4 mono	108	056	C	—	2003-12-25	5.6 m	
	LISS-3	108	056	—	50%	2006-01-31	23.5 m	—
	LISS-3	108	056	—	50%	2009-03-28	23.5 m	—
IRS Resourcesat-2	LISS-4 fmx	108	057	C	—	2012-01-12	5.6 m	—

1. SAT: Shift Along Track; 2. LISS-3 and Pan / LISS-4 mono scenes with close or same dates of pass were merged (pansharpened) for improvement of spatial resolution to 5.6 m in the images of 1997, 2001, and 2003.

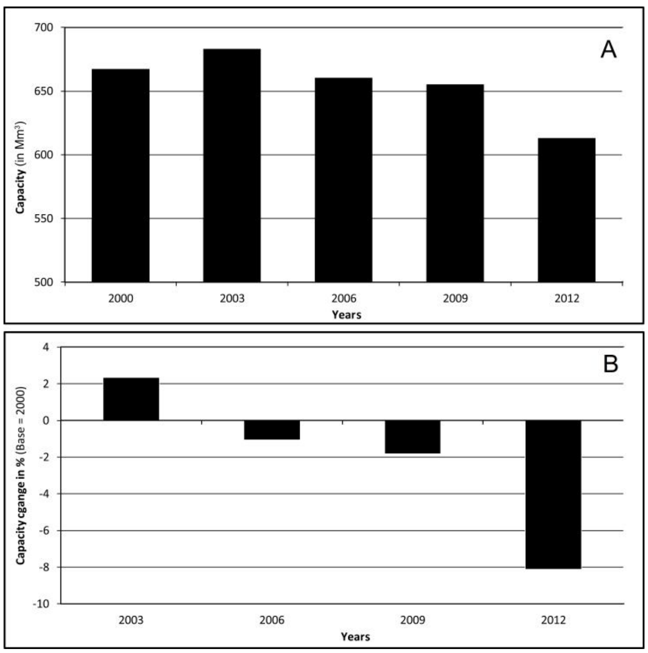

Fig. 3 — Capacity of the Balari Reach between 2000 and 2012, estimated on the basis of 1,405 depth points along 23 hydrographic profiles shown in the inset map of Fig. 2. (A) Actual data, (B) Percentage change from 2000.

The shrinkage and shallowing of the Haldia Channel has affected the capacity in this stretch and thereby the navigability and shipping. Total capacity of the reach decreased from 667.4×106 m^3 in 2000 to 613.21×106 m^3 in 2012 — a change of 8.13% (Fig. 3). This occurred due to the choking up of the Haldia channel. Although the Rangafalla Channel had showed some improvement during this period, it has not been reflected in the capacity of the reach.

The 1997–2012 study of the configuration of the Balari shows the gradual growth of the bar, which evolved into an island by 1997 (Fig 4). The island not only increased in area, but also migrated southwards choking up the northern portion of the dock area of the HDC which houses an oil jetty and restricted the berthing of large oil tankers. In Fig. 5, change in the supratidal area of the Balari Island is represented graphically. It shows the gradual increase in area from 0.29 km^2 in 1997 to 3.83 km^2 in 2012.

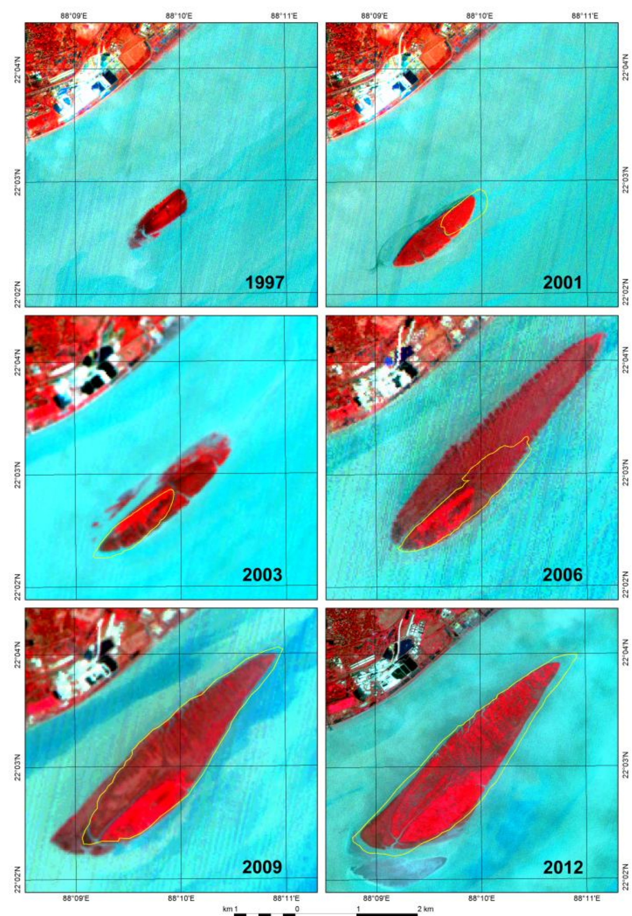

Fig. 4 — Changes in the configuration of the Balari Island represented in satellite images: 1997–2012. *Source*: see Table 2.

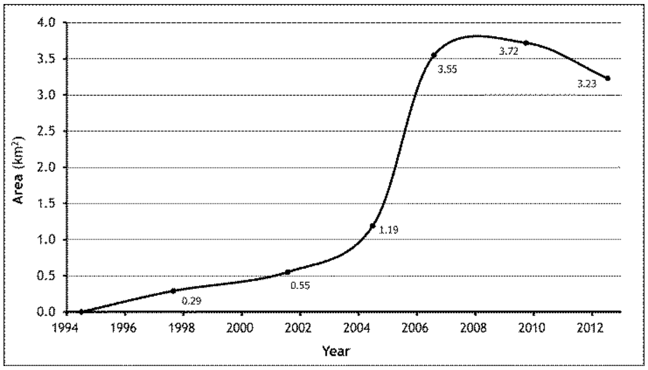

Fig. 5 — Changes in the area of the Balari Island: 1997–2012. *Source*: see Table 2.

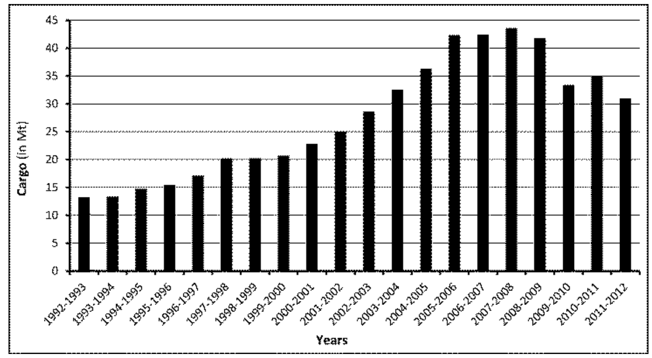

Fig. 6 — Cargo handled in million tonnes in Haldia Dock Complex. *Source*: Kolkata Port Trust Administrative Reports (1992–2012).

Anticipating the growth of the Balari Bar, a comprehensive river training work was planned in the early 1980s. The main aim was to divert a significant amount of ebb flow into the Haldia Channel. The highlights of the project were to construct a 2.8-km long guide wall at the northern tip of the Nayachar island and an 8-km long guide wall at the southern tip of the island, both to guide the ebb and the flood tides into the Haldia Channel.[6] Of these, only the construction of the northern guide wall was taken up and was completed in June, 1992. Contemporaneously, according to an agreement reached in 1990, the recessional dredging project was handed over to a Dutch company, specialised in riverbed bulk shore disposal dredging. Shore disposal of dredged material technique was important here because channel disposal, which is practiced by the Indian dredgers, could return the sediments to their place of origin. The project failed as the strong tides dismantled the pipelines connected with the dredger for the shore disposal of the dredged materials.[16] Since then, any attempt of capital dredging has not been done in this reach and the Jiggerkhali Flat and Balari Bar have remained untouched except for some maintenance dredging.[23] As a consequence, the gradual deterioration of the Haldia Channel restricted the movement of ships from HDC to KDS through it. By 1994, the Balari Bar had become stable and its area and height started to increase. Every year an additional 4 million m^3 of dredged material (bed sediments) is lifted from around the HDC to keep it open to traffic.[24,25] With time, the Balari Bar expanded vertically as well as longitudinally choking up the northernmost oil jetty of HDC (Oil Jetty 1) where the draft falls to 5 m or less becoming virtually impossible to accommodate Suezmax vessels. It also becomes difficult to accommodate Panamax vessels during post-freshet months. Tangible effect of the deterioration of the Haldia Channel due to southward extension of the Balari Bar is noticed from drop in the cargo handling of the HDC since 2009 (Fig. 6). Cape-size vessels that carry crude oil, also known as Very Large Crude Carriers and Ultra Large Crude Carriers, were never able to enter the HDC. These would anchor at the Sandheads during fair weather conditions and unload crude to daughter vessels bound for HDC. To facilitate an uninterrupted supply of crude, the Indian Oil Corporation started pumping oil to its refinery at Haldia from Paradip, Odisha, through a pipeline [26] adding to the drop in HDC's crude cargo.

At present, regular maintenance dredging is done here to keep the channel and the berths open to ships and smaller oil tankers. The KoPT, supplemented by the Government of India, has to shell out huge amounts for this maintenance dredging. Capital dredging of the channel is due for almost a decade now. Consequently, the ships travelling from HDC to Kolkata docks have to skirt the southern tip of the Nayachar Island and take the Rangafalla Channel and travel extra distance.[16] The Rangafalla Channel, unfortunately, is not very stable and its thalweg is prone to shifting as observed in the cross-profiles (Fig. 2). Skilled river pilots are maintained by KoPT for guiding the ships from the offshore anchorage to the HDC with the help of navigational charts and advanced positioning systems. The northern part of Haldia Channel is now abandoned for shipping.

Conclusions

For a number of years, the HDC acted as the major dock system for the KoPT, handling all the ocean liners. Since its decline started from 2008, the total percentage of cargo handled by the KoPT is facing a falloff and the port is facing a severe competition from the neighbouring sea ports. Several measures have been proposed by the KoPT authorities which include capital dredging over Jiggerkhali Flat (10 km long, 450 m wide at the top, 200 m at the bottom and 4.5 m deep), trimming of the eastern side of Haldia Channel, construction of southern guide wall at the western side of Nayachar Island off HDC and bank protection near the Sondia Column [20] and other river training measures to improve the condition of the Haldia Channel and thus save the HDC from premature closure. To utilise year-round benefit from adequate draft, a new port at southwestern Sagar Island at the mouth of the Hugli Estuary is also envisaged.

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References

1 Basu S R & Chakraborty S C, Some considerations on the decay of the Bhagirathi Drainage System, edited by Bagchi K (Calcutta University, Calcutta), 1972, pp 57-77

2 Sen A, The Decay of the river Hugli and its impact on the Port of Calcutta – A Geographical Appraisal, Unpublished PhD Thesis, Geography Dept., Calcutta University, Calcutta 1998, 54–59

3 Parua P K & Das S C, Bank Erosion of Bhagirathi-Hooghly river in the Post Farakka period, Proc National Sem on Impact of Water Resources Development on Environment (Indian Association of Hydrologists, West Bengal Regional Centre, Calcutta), 1994, 1–11

4 McDowell D M & O'Connor B A, Hydraulic Behaviour of Estuaries (Macmillan Press, Cambridge) 1977, pp 292

5 Sanyal T & Chatterjee A K, The Hugli estuary: A profile, in Port of Calcutta: 125 Years Commemorative Volume, edited by Chakraborty S C (Calcutta Port Trust, Calcutta) 1995, pp 45–54

6 Ghotankar S T, Tidal propagation in the Hooghly, in Bhagirathi-Hooghly Basin: Proc Interdisciplinary Symp, edited by Bagchi K (Calcutta University, Calcutta) 1972, pp 127–132

7 Ghosh S N, Assessment of relative movement of sediment in a tidal reach with special reference to navigation in river Hooghly, ISH J Hydraul Eng, 6(2000) 1–11

8 Bhaskaran P K, Mangalagiri S & Bonthu S, Dredging maintenance plan for the Kolkata port, India, Curr Sci, 107(2015) 1125-1136

9 Wells J T, Tide dominated estuaries and tidal rivers, in Geomorphology and Sedimentology of Estuaries, edited by Perillo G M E (Elsevier, Amsterdam) 1995, pp 179–204

10 Sau, S N, Economics of Calcutta-Haldia Port Complex, Economic and Political Weekly, 5 (1990) 1015–1026.

11 Sau S N, Port and Development (Firma KLM Pvt Ltd, Calcutta) 1997, pp 244

12 Roy S C, Hydraulic Investigations on behalf of Hooghly Estuary, (Metteilungen des Franzius, Inst fur Grund-und-Wasserban der Technischen Uni Hannover) 1969, pp 149

13 Hiranandani M G & Ghotankar S T, Balari Bar and Regime of Hooghly Estuary: Technical Memorandum NAV-2, (Central Water & Power Research Station, Pune) 1961, pp 42

14 Bandyopadhyay S, Coastal changes in the perspective of long term evolution of an estuary: Hugli, WB, India, in Quaternary Sea Level Variation, Shoreline Displacement and Coastal Environments, edited by Rajamanickam, V & Tooley, M J, (New Academic Publishers, New Delhi) 2000, pp 103–115

15 Banerjee A P, Majumder A & Dutta S, A Study on the ever changing physical regime of the inner estuary of the river Hooghly, ARPN J Eng Applied Sci, 8(2013) 1071–1080

16 Ray A C, Maritime India: Ports & Shipping, (Pearl Publishers, Calcutta), 1993, pp 159–182

17 Chakrabarti P, Process response system analysis in the macrotidal estuarine and mesotidal coastal plain of eastern India, in Quaternary Deltas of India: Memoir 22, Geological Society of India, edited by Vaidyanadhan, R, (Geological Society of India, Bangalore), 1991, 65–181

18 Kumar K, Palit A, Chakraborti A K, Bhan S K, Chowdhury B & Sanyal T, Change detection study of islands in Hooghly estuary using multidate satellite images, Photonirvachak: J Soc Remote Sensing, 22(1994) 1–7

19 Prithviraj M, Sengupta S, Ghosh S K, Ramanas I & Chakraborty D, Documentation of the long term coastal geomorphic changes within the Hugli river estuary, India, Asian Pacific Remote Sensing J., 7(1995) 1–9.

20 Bandyopadhyay S, Mukherjee D, Bag S, Pal D K, Das R K, & Rudra K, 20th century evolution of banks and islands of the Hugli estuary, West Bengal, India: Evidences from Maps, Images and GPS survey In Geomorphology and Environment, edited by Singh, S, Sharma, H S & De, S K, (ACB Publishers, Kolkata), 2004, pp 235–263

21 Ghosh T, Bhandari G & Hazra S, Coastal Erosion and flooding in Ghoramara and adjoining islands of Sundarban deltaic system, in Analysis and Practise of Water Resource Engineering for Disaster Mitigation, Proceedings International Conference on Water Related Disaster, Kolkata (New Age International Pvt Ltd, New Delhi), 2002, 38–41

22 Survey of India, Hugli River Tide Tables, (Dehradun) 2011 pp 174

23 Calcutta Port Trust, Proposal for the execution of River corrective work for maintenance of river depth in Jellingham-Haldia-Balari channel, in unpublished agenda and proceedings of Board Meeting, 4, 1996, 40–47

24 Calcutta Port Trust, Port Performance in Administrative Reports 1990–2012

25 Calcutta Port Trust, Dredging Statistics, in Unpublished Report: Calcutta in 2001: Problems of the Navigability of River Hooghly, 1994, pp 12

26 Kolkata Port Trust, Development of Business Plan for Kolkata Port Trust, in Revised Interim Report, Haskoning India Pvt. Ltd. In associations with Crisil Infrastruture Advisors, 2007, pp 20–46