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COASTAL EROSION IN THE TROPICAL RAPID ACCRETION DELTA – A CASE STUDY OF THE RED RIVER DELTA, VIETNAM

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The Red River has formed the largest plain in the North Vietnam. Sediments transported from the river system accumulate mainly around some big river mouths (Tra Ly, Ba Lat, Lach and Day) leading to rapid accretion at the coast (up to 100m/y). However shoreline retreat has long been recognized as a serious problem in the region. The segments of severe erosion are distributed either between the mouths or nearby them. The reasons of erosion are the wave-induced longshore sediment transport and the deficit of sediment provided from the river mouths. The erosion is entirely strengthened by influences of dike systems, dams upstream, and locally affected by human activities on the coast. The long-term measures against coastal erosion should focus on the scour at the seadykes which can include reinforcement of seadykes by groins, geotubes and internal standby dikes at the severe erosional coast of Dong Long, Hai Hau, Nghia Phuc; reinforcement of seadykes by revetments and re-cultivation of mangrove at the locations of weak erosion.

Key Words : *Red River Delta, accretion, erosion, sediment transport*

1. INTRODUCTION

The Red River delta coast is a part of the west coast of the South China Sea (**Fig. 1**). The area is one of the highest population density in Vietnam. Herein the interaction between the sea and big rivers of the Red River system has created a typical tropical natural condition which is suitable for tourism and agricultural, aquaculture development.

The Red River delta coast belongs to the river dominated coast (**Fig. 2**).The annual amount of sediment transported by the Red River system into the South China Sea is about 82 x 10^6 m^3. In the wet season (from June to January), about 90% of the annual sediment supply is transported through the various distributaries (Nhuan et al., 1996). Of the total amount of sediment supplied, 11.7% passes through the Van Uc and Thai Binh river mouths, 11.8% through the Tra Ly river mouth, 37.8% through the Red River (Ba Lat) mouth and 23.7% through the Day river mouth. These major river mouths represent very rapid accretion zones where sediment accumulation rates exceed sea level rise (1-2 mm/year) and tectonic subsidence (2 mm/year, Ngoi et al., 2000).

The northern part of the coast (from Ba Lat to Haiphong) has a diurnal tidal regime with an average amplitude of 2.5-3.5m. In the southern part, from Ba Lat to Ngason, the tide is mixed with a diurnal dominance. The average tidal amplitude is 2-3m. Waves usually have a dominant direction from the east, northeast during the dry season (October - March) and from east, southeast during the wet season (April - September). The average and maximum wave heights are 0.7-1.3 m and 3.5-4.5m, respectively, but in severe storms wave heights can reach over 5 m (Nhuan et al., 1996).

The large amount of sediments transported from the Red River system has led to a rapid accretion delta, especially around some big river mouths (Tra

Ly, Ba Lat, Lach and Day) where the accretion can be up to 100m/y on average. Most of the sediment accumulates near the mouths leading to severe shoreline retreat in some places. The erosion is now a serious obstacle for the economic development in the coast. In order to contribute to solve the problem of erosion the paper elucidates the shoreline change in the recent time and the physical mechanism of erosion. In the paper the mechanism of coastal erosion is mainly analyzed for the coast of Hai Hau district - the most severe erosional coast in Vietnam. The results then can help to propose preventive solutions against coastal erosion.

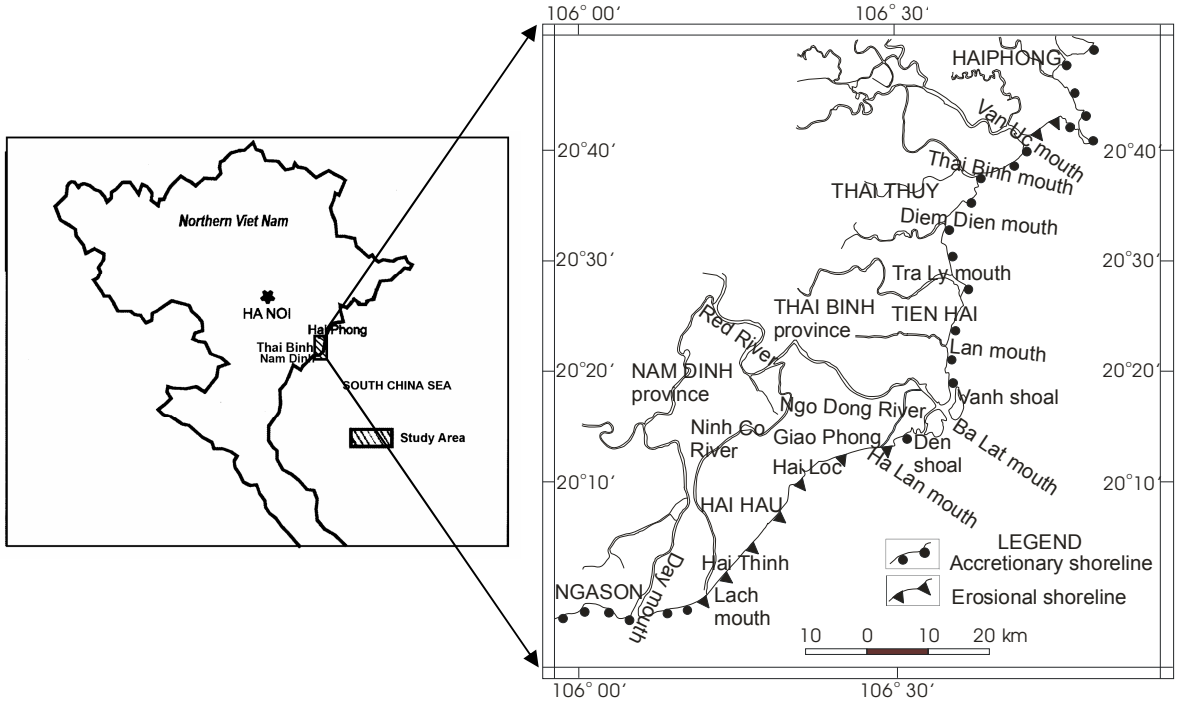

Fig. 1 Location of the study area (Duc et al., 2007).

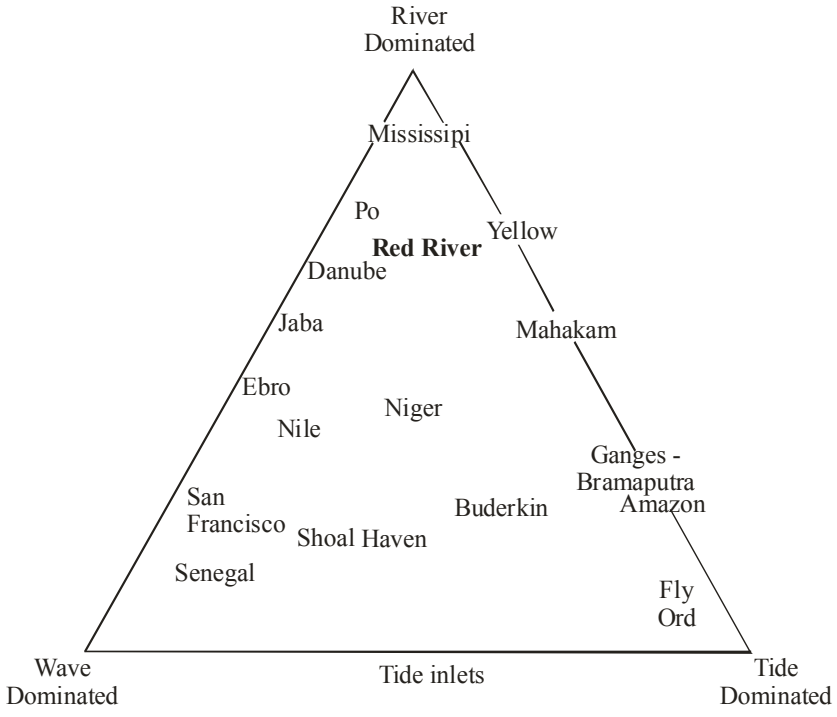

Fig. 2 The Red River in the chart of delta classification of Coleman & Wright (1975).

2. SHORELINE CHANGE IN THE RED RIVER DELTA

The analysis of topographical maps scaled 1/50,000 and 1/25,000 in recent time with the help of a GIS software (MapInfor) shows qualitative figures of shoreline change at the coast of the Red River delta. **Table 1** gives an overview that the main trend of the delta is rapid accretion, especially at the big mouth such as Tra Ly, Ba lat and Day mouth. However the shoreline is not step by step forwarding to the sea. Firstly a sandy bar is formed in front of the mouths. Then the bar protects the shoreline behind against wave and current attacks that makes a suitable condition of rapid accretion. When the shoreline apparently connected to the current bar a new bar normally formed with the crest above the mean tide. The average velocity of accretion is 65 m/y (1930-1965), 84 m/y (1965-1985) and 60 m/y (1985-1995) at the Ba Lat mouth and 95-110 m/y at the Day mouth.

The severe erosional coast are also recognized which have the length and area much less than those of accretionary coast. The distribution of erosional shoreline can be a typical character of the Red River delta. They are either in the middle of the big mouths (Hai Hau district) or very close to them (Giao Phong, Nghia Phuc).

Table 1 Accretion and Erosion at the Red River Delta Coast

Segment	Accretion			Erosion		
	Length (km)	Avg. Velocity (m/y)	Area (ha)	Length (km)	Avg. Velocity (m/y)	Area (ha)
1930 - 1965						
Thai Binh - Diem Dien mouth (I)	10,0	28	28	-	-	-
Diem Dien - Lan mouth (II)	31,4	11	34,5	5,6	3,5	2,0
Lan mouth - Giao Phong (III)	4,5	65	29,3	9,5	12	11,4
Giao Phong - Hai Thinh (IV)	14,0	5	7,0	13,5	5,5	74,3
Lach mouth (V)	4,0	27	10,8	0,5	2	0,1
Day mouth (VI)	17,0	95	161,5	-	-	-
1965-1985						
Segment I	8,4	24	20,2	1,6	15	2,4
Segment II	30,8	16	49,3	6,2	6	3,7
Segment III	6,5	84	54,6	7,5	8	6,0
Segment IV	7,2	6	4,3	20,0	9	18,0
Segment V	4,0	35	14,0	0,5	10	0,5
Segment VI	29,3	110	322	0,8	3	0,2
1985-1995						
Segment I	8,8	16	14,1	1,2	3	0,4
Segment II	32,5	12	39,0	4,5	4,5	2,0
Segment III	11,5	60	69	2,5	2,5	0,6
Segment IV	8,0	4	3,2	19,2	11	21,1
Segment V	4,0	28	11,2	0,5	12	0,6
Segment VI	30,0	100	300	1,5	4	0,6

3. COASTAL EROSION IN HAI HAU DISTRICT

Hai Hau is a district in costal zone of Nam Dinh province that has been formed by deposition process of the Red River delta system. With the population density of 1,400 persons/km^2, Hai Hau is a great important economic place of Nam Dinh province with of 54% and 53% of sea and salty production, respectively. The shoreline is a straight line directing from Northern East to Southern West in a distance of about 27 km. The slope is 1:40 in near the shore, and it is from 1: 350 to 1: 200 at the depth of over than 1 m. The slope decrease as the sea water depth increases. The shoreline is covered by fine sand with the thickness of 0.5 - 2m. That sandy layer is thinner seaward. The tidal amplitude is 2.5–3 m. Waves have main directions of East, Northeast in dry season and East, Southeast in wet season. The average height of waves is 0.7 - 1.3m and reach to 3.2 m in storms. The Hai Hau coast includes 7 communes such as Hai Loc, Hai Dong, Hai Ly, Hai Chinh, Hai Trieu, Hai Hoa, and Hai Thinh. Herein, the erosion has caused great damages on the local infrastructure and even loss of lives that leads to significant disadvantages for social-economic development in the region.

The erosion in Hai Hau district has started since the beginning of the 20th century (from 1905). This erosion has a close relation to the degradation of the Ha Lan river mouth (the former main river mouth of the Red River system at that time). The clear evidence of the Ha Lan mouth degradation can be found at Giao Long, Giao Phong shoreline where was continuously deposited with great speed (reaching to 100 m/year in some segments during the period of 1905-1930) (**Fig. 3**). However the shoreline was then changed to erosion. The main river mouth was shifted to the Ba Lat the mouth. The length of erosional segment increased gradually to the 1980s, then it has a tendency of shortening because the shoreline was protected by the sea dike system. However, the erosion intensity increases clearly from 1985 to 1995, more 1.5 times than from 1965 to 1985 (**Table 2**). Especially, the erosion speed reaches 15-20m/year at the Hai Chinh – Hai Hoa shoreline. The erosion usually takes place stronger in the northeast wind season and has a tendency of moving southwestward to Hai Thinh commune with of the average speed of 400m/year.

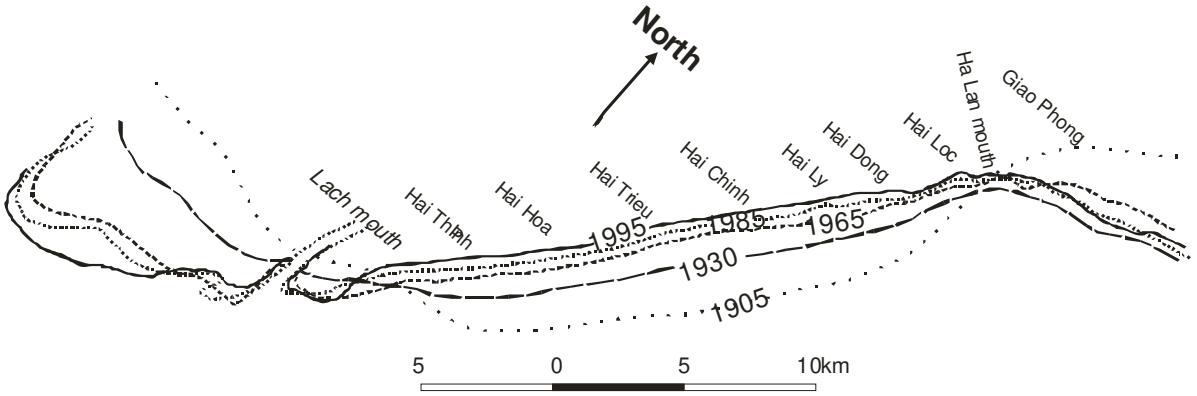

Fig. 3 Shoreline change of Hai Hau coast and surrounding area.

Table 2 Coastal erosion in Hai Hau district

Commune	***The average erosion rate (m/year)***				
	1905-1930	1930-1965	1965-1985	1985-1995	1995-1999
Hai Loc	Accretion	Accretion	8	5	0
Hai Dong	*5*	*6*	*12*	*10*	*0**
Hai ly	*4*	*6*	*10*	*7*	*0**
Hai Chinh	*3*	*2*	*8*	*11*	*15*
Hai Trieu	*3*	*4*	*9*	*13*	*20*
Hai Hoa	*2*	*3*	*8*	*12*	*21*
Hai Thinh	Accretion	Accretion	Accretion	Accretion	*7*
The total length of erosion (m)	*10.800*	*13.500*	*20.000*	*19.200*	*17.200*

(- the horizontal erosion rate = 0 because of the sea dikes)*

Nowadays, the shoreline from Hai Loc to Hai Dong has been changed to accretion; however the erosion can continue to increase in other segments. The most severe erosional segment is now shifting to Hai Thinh commune. It is very clear by a series of 3 photos taken at the same place in the coast of Hai Thinh commune from 2003 to 2005. **Figures 4 and 5** show that during 10 months (from 02 September 2003 to 25 July 2004) a small tent for mineral exploitation was almost disappeared. The shoreline retreated about 30 m. Nine month later all the pine trees were also destroyed. The shoreline reached to the seadyke with a retreat of about 40-50 m (**Fig. 6**).

Fig. 4 Hai Thinh, 02 September 2003.

Fig. 5 Hai Thinh, 25 July 2004.

Fig. 6 Hai Thinh, 17 April 2005.

In front of the sea dykes, the shoreline does not keep moving landward and erosion changes from horizontal to vertical direction that lowers the tidal flat and scouring of the dikes. The tidal flat is lowering with high rate at the severe segments such as Hai Ly, Hai Chinh, Hai Trieu and Hai Hoa commune (15-25 cm/year). The erosion has decreased in Hai Dong where lowering rate is 6.3 – 6.7 cm/year.

4. THE REASONS OF COASTAL EROSION IN HAI HAU

Hai Hau coastal zone is situated between two big river mouths such as Ba Lat in the north and Lach Giang in the south. The annual sediment amounts transported through these river mouths are 29.1 and 5.82 tons (period 1956 – 1998), respectively. According to the method of Gao & Collins, 1992, the net sediment transport pathways are referred from grain-sizes (**Fig. 7**). It shows that the sediment from the Balat mouth is not deposited nearshore, but moves seaward up to the water depth of 25 m. It is clear in the Giao Long - Hai Loc segment at the depth of 5-25m. In Hai Thinh shoreline, the sediment is transported along the coast southwestward. In Giao Long- Giao Phong shoreline, the sediment is transported along coast northeastward. Its reason may be the waves created by northeast winds do not have strong effect on the segment because of the sandy bars in front of the Red River mouth. The seacoast is eroded by southeast wave and the sediment is transported southwestward. The alongshore sediment transport is calculated by the equation of *Manual of Coastal Engineering* (U.S. Army Corps of Engineers, 2002), with the wave monitoring data at Hai Hau from 1976 to 1994. The result of (Duc, 2002) shows that the volume of alongshore sediment transport southwestward is 654,078 m^3/year. The sediment is mainly transported to the southwest by the northeast and east waves. Some periods in summer, the dominant wind direction is southeast and south, and in such cases the sediment is transported northeastward with the average volume of 62,884 m^3/year. However, the net alongshore sediment transport is southwestward. The volume of cross-shore sediment transport is 1,286,322 m^3/year. Therefore the sediment volume moved out of the near shore zone is 1,940,000m^3/year (38% along the seashore and 62% far away).

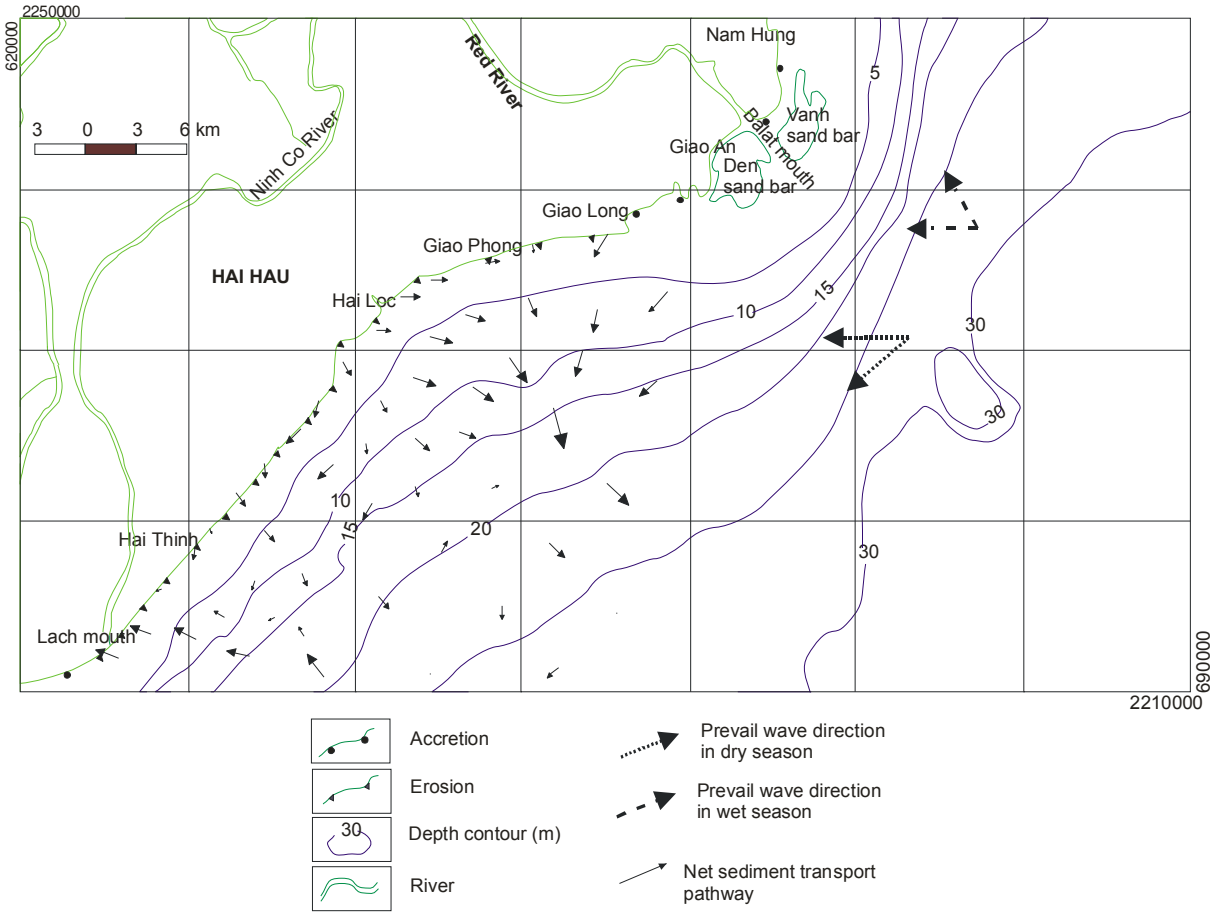

Fig. 7 Net sediment transport pathway at the Hai Hau coast.

5. DISCUSSIONS

Along the coast of the Red River delta, the sediments provided by the big mouths (Tra Ly, Ba Lat, Lach, and Day) are mainly deposited at shallow sea and form sandy bars in front of the mouth. The shoreline near the mouth therefore has not sediment supply, leading to erosion. When the crest of the sandy bar is above the mean tide it can be protect the behind shoreline from wave attack, and the shoreline changes to be accreted.

The most severe erosion in the coast is related to the degradation of river mouth. Before 20th century Ha Lan was the main mouth of the Red River and the Hai Hau coast was rapid accretion. The Ha Lan mouth then was degraded and the main mouth change to Ba Lat leading to the erosion in Hai Hau. At the present some mouths are degrading such as Lan and Thai Binh. These areas are turn to weak to moderate erosion. Fortunately the planted mangrove forests have effectively protected these areas.

The shoreline change in a near future has a trend of more severe erosion and lower accretion. The average rate of sea level rise is 2.24 mm/year (Nhuan et al., 1996). According to the equation of Brunn (1962), the erosion rate in Hai Hau will be raised 0.2- 0.25m/year. By using the one-line model forecast, the erosion rate here will be raised 6-8m/year in 2010.

The river dike system reduces the flow channel, increasing the flow power to the sea, and decrease sediment supply to the region near river mouths. The Red River dike also plays important role to set up the fact that the delta only develops strongly in the north (Van Uc, Tra Ly river mouths), center area (Ba Lat river mouth), and in the south (Lach, Day mouths). The area between the rivers mouth are not supplied with sediments leading to erosion segments, among that Hai Hau is a typical case.

The upstream hydropower plants such as Hoa Binh hydropower plant reduce 56% the sediment supply to the down stream. The accretion rate decreased from 84m/year (1965-1985) to 60m/year (1985-1995) at the Ba Lat mouth. In the near future, as Tuyen Quang, Son La and other hydropower plants will be operating the sediment supply for the coast is going to decrease significantly. Therefore the reduction of accretion at the river mouths and more severe erosion in the Hai Hau coast could be occurred.

Before 1998, the dike was built manually with 4m in height, 1: 2 in slope. The sea side was covered by rock with average size of 30cm. This dike system is weak and has a high vulnerability in typhoon. To

mitigate the damages as the dike destroyed, the standby dike system was built with a distance of 150-200m from sea exposed dikes. Actually, both two dike systems are weak and can stand for short time. They were almost disappeared after 10 years on average. Nowadays, most the dikes in Hai Hau were rebuilt with concrete. It is much stronger but they still can not suffer from surge storms in spring tide. Moreover, the problem of scouring is not rationally solved. The activity of the building material and mineral exploitation in Hai Thinh coastal zone a few years ago also led to stronger erosion in the region.

With the high population density and economic benefits, the protection of the Hai Hau costal zone is very important. The erosion has bad direct impacts to the sea dike stability, reduces the area of land for living, mangrove forest, aquaculture and agriculture; at the same time it increases saline intrusion, making difficult condition for tourist development, and salty production. Especially, as before years, the surge storms destroyed sea dikes and people had to move to other safe places. In fact, the sea dike system in Hai Hau was built strongly with the investment of PAM since 1998. The dike was covered by polygonal pre-cast concrete with the mass of 100 kg, even reaching to 200kg on the slope of 1: 2.2-3. The height of dikes extends to + 4.5-5.5 m. The dike footing was placed at the depth of 1.5 m. This dike is effective but the cost is high (5-7 million VND/m). However with the rate of lowering tidal flat as presented above, the dike footing will be destroyed in 6-10 years in the most severe erosional segments. Therefore, the additional construction is needed to support the sea dike system. The solution should be used such as groins with length of 120m, the slope of $1.5 - 2^0$. The groins are built by the cementing steel rod tube with thickness of 10cm, diameter of 1m, and placed continue in the depth of 0.5m under tidal flat, the height of 1.5m with the sand bag inside. The distance between the soldering is 80m. The construction needs a combination with periodic monitoring, maintaining, repair and upgrade. Besides the area where has been changed to accretion as Hai Loc needs starting to plant mangrove forest.

6. CONCLUSIONS

1. The sediments supply of the Red River system only concentrate at the big mouths (Tra Ly, Ba Lat, Lach Giang, and Day) leading to the formation of sandy bars in front of the mouths. When the crest of the sand bar is above the mean tide it can be protect the behind shoreline from wave attack, and the shoreline then change to be rapid accretion.
2. The segments of severe erosion are distributed either between the mouths or nearby them. The erosion is due to the wave-induced longshore sediment transport and the deficit of sediment provided from the river mouths.
3. The sea level rise and human activity, especially the building of upstream hydropower plants have strongly impacts of both spatial and temporal changes of the shoreline. The coastal erosion is expected to be more severe and some new severe erosional segments can be formed.
4. The counter measures against coastal erosion can include reinforcement of seadykes by groins, geotubes and internal standby dikes at the severe erosional coast such as Hai Hau; reinforcement of seadykes by revetments and re-cultivation of mangrove at the locations of weak erosion.

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