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MONITORING COASTLINE CHANGE IN THE RED RIVER DELTA USING REMOTELY SENSED DATA

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ABSTRACT: *This study focuses on the use of remotely sensed data for monitoring coastline changes in the Red River Delta during the 1998 to 2008 period. For the satellite image data processing, the shoreline was defined as the mean sea level on the muddy coast where the tide is the dominant dynamic factor and as the mean high sea level on the sandy coast where the ocean waves are the dominant dynamic factor. A GIS approach was used for the quantitative analysis of coastline change. It was observed that the coastline change in the Red River Delta underwent complicated changes during this 10 year period. In this period, the accretion rate in Red River Delta coastal area was about 10,256ha and the erosion rate was about 542ha. In the Hai Hau and Hau Loc coastal areas, erosion occurred in a large scale and was very intense. Along other coastlines of the Red River Delta, sediment accretion dominated at rates of over 30m/year. These zones of varying erosion and accretion have important implications for coastal zone management in the Red River Delta region.*

Keywords: Red River Delta, erosion, accretion, coastal zone management, remote sensing, geographic information system.

INTRODUCTION

Monitoring coastal erosion and accretion using remote sensing data is a good solution to overcome the challenges that traditional monitoring methods face to in coastal environmental management. In assessment of coastal change, in a given period of time, the integration of image data with other geo-data into Geographical Information Systems (GIS) is a powerful tool for quantitative spatial data analysis [10].

The Red River Delta coastal zone is about 120km long from Do Son to Lach Truong, about 17,000km^2 in area, less than three meters above sea level, and much of it is one meter or less, and houses many important socio-economic and residential areas in the Northern Vietnam. During recent decades, the coastal change in this zone has occurred in a complicated manner. Significant climatic and environmental events can cause sea dykes to be broken and bring terrible disasters to the populous residential areas behind the dykes [11]. Monitoring of the coastal change in the Red River Delta has been conducted previously in a number of studies [1, 5, 6, 8] and comprehensively reviewed by Thanh et al. [9]. However, the results of these studies were neither systematic due to a limitation in the data collected. A recent study [3] used remotely sensed data, published topographic maps and field survey data within a GIS environment to monitor the coastal change in the Red River Delta during the 1930 to 1998 period with reliable results. This study is to continue the monitoring of the coastline

changes in the Red River Delta for the 1998 to 2008 period using remotely sensed data. This paper recorded changes in the location and magnitude of the accretion and erosion processes affecting the Red River Delta coastline during this period.

MATERIALS AND METHODS

Main materials for this study include two scenes of SPOT 4 acquired on the 21st December 1998 and 20th March 2008 topographic UTM maps at scales of 1:50,000 and 1:25,000 published in 1998 and tidal data collected from the Vietnam Navy Force. A field survey to characterize the tidal flats was carried out from the 4th to 10th March 2008. This survey measured the height of the flat, the position of the eroded cliffs and the width of the flat. Observations of the surrounding terrain and the direction of the ocean and river currents were conducted and photos and videos were taken. GPS was used to accurately locate of the shoreline at survey time.

Coastline in the study area is identified on satellite images by the combination of satellite image resolution and coastal dynamics and geomorphology. In the areas of strong erosion, such as Hau Loc and Hai Hau, recognized by linear cliffs and beaches, the coastline was defined as the highest tidal level. The highest tidal level coincides with the foot of the cliff and the landward beach boundary. In muddy accreted areas, such as river mouth areas, the coastline was identified as the boundary between the tidal flats and mangrove forests.

SPOT multi-spectral satellite images, with 20 m spatial resolution and geometrically corrected to UTM geographic coordinates using the 2000 Vietnam Projection datum and enhanced to better identify the coastline, were used for detecting the coastline. Then extracted data were overlaid in GIS to calculate the difference between the geographic positions of the coastlines [2] and finally to get the area, length and the average rate of erosion or accretion [3] in the following relationship:

$$R = A / L \quad (1)$$

Where R is the average rate of erosion or accretion for the 1998 to 2008 period, A is the area of erosion or accretion (ha), and L is the length (km) of erosion or accretion. Two kinds of output include the map of the multi-temporal coastlines and erosion/accretion, and the data file of summary statistics of changes in coastline parameters [3]. The assessment of coastline change in Red River Delta is according to scale and intensity of erosion/accretion [3].

RESULTS

Do Son - Tra Ly coastal part

In the period from 1998 to 2008 in the Do Son - Tra Ly coastal zone, accretion was very strong, both in intensity and scale, along the coast (figure 1) with a total area of accretion reaching 2,900 ha along a 54km long coastline at an average rate of about 50m per year (table 1). Erosion occurred at two coastal segments in the Thai Do Commune of Thai Thuy District, Thai Binh Province with different intensity and scales. The total eroded area was about 89ha along a 5.86km long coastline at an average rate of 11m per year (figure 1).

Table 1. Erosion/accretion in the Do Son - Tra Ly coastal zone in 1998 - 2008

Province	*District*	*Commune*	*Area (ha)*	*Length (m)*	*Rate (m/year)*	*Intensity*	*Scale*
Hai Phong	Kien Thuy	Bang La - Dai Hop	501.10	8,301	+ 60.3	Very strong	Very large
	Tien Lang	Vinh Quang - Dong Hung	1,079.26	13,202	+ 81.6	Very strong	Very large
			499.82	7,632	+ 65.4	Very strong	Very large
		Thai Thuong	178.77	4,859	+ 36.7	Very strong	Very large
	Thai Thuy		3.98	892	- 4.5	Medium	Medium
		Thai Do	84.70	4,966	- 17.0	Very strong	Very large
Thai Binh			470.70	12,889	+ 36.4	Very strong	Very large
	Tien Hai	Dong Long	171.23	7,164	+ 22.5	Very strong	Large

Note: - is erosion, + is accretion

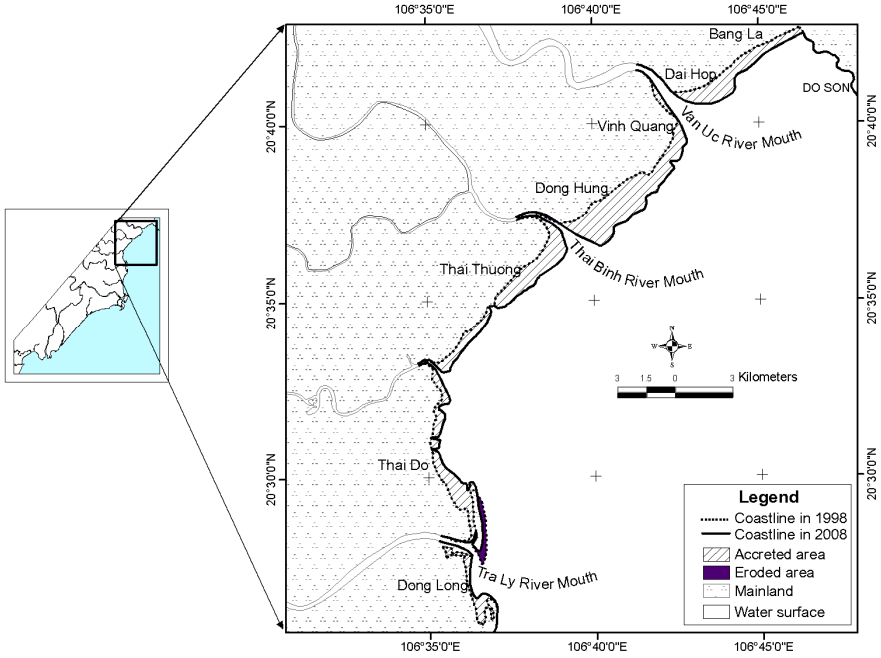

Figure 1. Map of erosion/accretion of Do Son - Tra Ly coastal zone from 1998 to 2008

Ba Lat River Mouth

Like the Do Son - Tra Ly coastal zone, accretion was very strong, both in intensity and scale, in the area near the Ba Lat river mouth (figure 2) with total area of about 4,390ha along a 64.3km long coastline at an average rate of about 36m per year (table 2). There were three coastal segments eroded in the Con Vanh Commune of Tien Hai District, Thai Binh Province and one at the Con Lu Commune of Giao Thuy District, Nam Dinh Province with a strong intensity and a medium scale of erosion. The total eroded area was about 67ha along a coastline 5.78km long at an average rate of about 11.6m per year (figure 2).

Table 2. Erosion/accretion in the Ba Lat River mouth in 1998 - 2008

Province	*District*	*Commune*	*Area (ha)*	*Length (m)*	*Rate (m/year)*	*Intensity*	*Scale*
Thai Binh	Tien Hai	Nam Thinh - Nam Phu	615.53	12,308	+ 50.0	Very strong	Very large
		Con Vanh	140.27	3,758	+ 43.0	Very strong	Large
			14.72	1,426	+ 10.2	Strong	Medium
			7.39	963	+ 7.6	Medium	Small
			28.80	2,466	- 11.6	Very strong	Large
			46.15	2,644	+ 17.4	Strong	Medium
			5.85	527	- 11.2	Very strong	Medium
			4.33	661	+ 6.4	Medium	Small
			29.87	1,720	- 17.2	Very strong	Medium
Nam Dinh	Giao Thuy	Giao Thien	47.31	33.58	+ 14.0	Strong	Medium
		Giao An	924.71	11,399	+ 81.2	Very strong	Very large
		Con Ngan - Con Lu	2,588.77	27,747	+ 93.2	Very strong	Very large
			2.80	1,067	- 6.4	Strong	Medium

Note: - is erosion, + is accretion

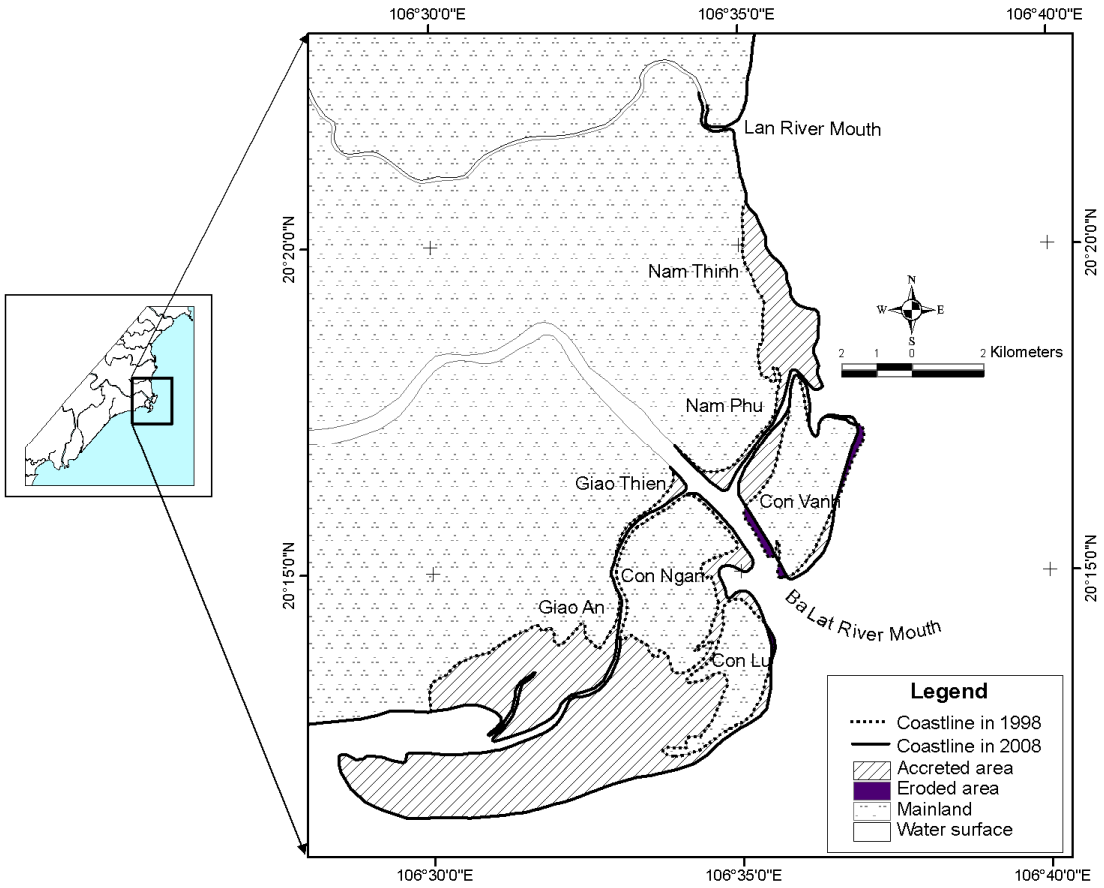

Figure 2. Map of erosion/accretion of Ba Lat River mouth in 1998 - 2008

So - Lach Giang coastal area

Unlike the two mentioned parts, erosion was strong, both in intensity and scale, along the So - Lach Giang coastal area (figure 3). The total eroded area is about 253ha along a coastline 20.3km long at an average rate of about 11m per year (table 3). Two sections of coastline were accreted, one at the Giao Lam Commune of Giao Thuy District and one at the Hai Loc Commune of Hai Hau District, Nam Dinh Province, both with a strong intensity and a medium scale of accretion. The total accreted area was about 140ha along a 7.834km long coastline at an average rate of 14m per year (figure 3).

Table 3. Erosion/accretion in the So - Lach Giang coastal area in 1998 - 2008

Province	*District*	*Commune*	*Area (ha)*	*Length (m)*	*Rate (m/year)*	*Intensity*	*Scale*
Nam Dinh	Giao Thuy	Giao Lam	132.94	7,116	+ 18.6	Strong	Large
	Hai Hau	Hai Loc	4.88	728	- 6.6	Strong	Medium
			6.78	719	+ 9.4	Medium	Small
		Hai Ly	103.20	4,539	- 22.6	Very strong	Large
		Hai Chinh	20.8	2,505	- 8.2	Strong	Large
			17.44	2,489	- 7.1	Strong	Large
		Thinh Long	107.23	10,101	- 10.7	Very Strong	Very large

Note: - is erosion, + is accretion

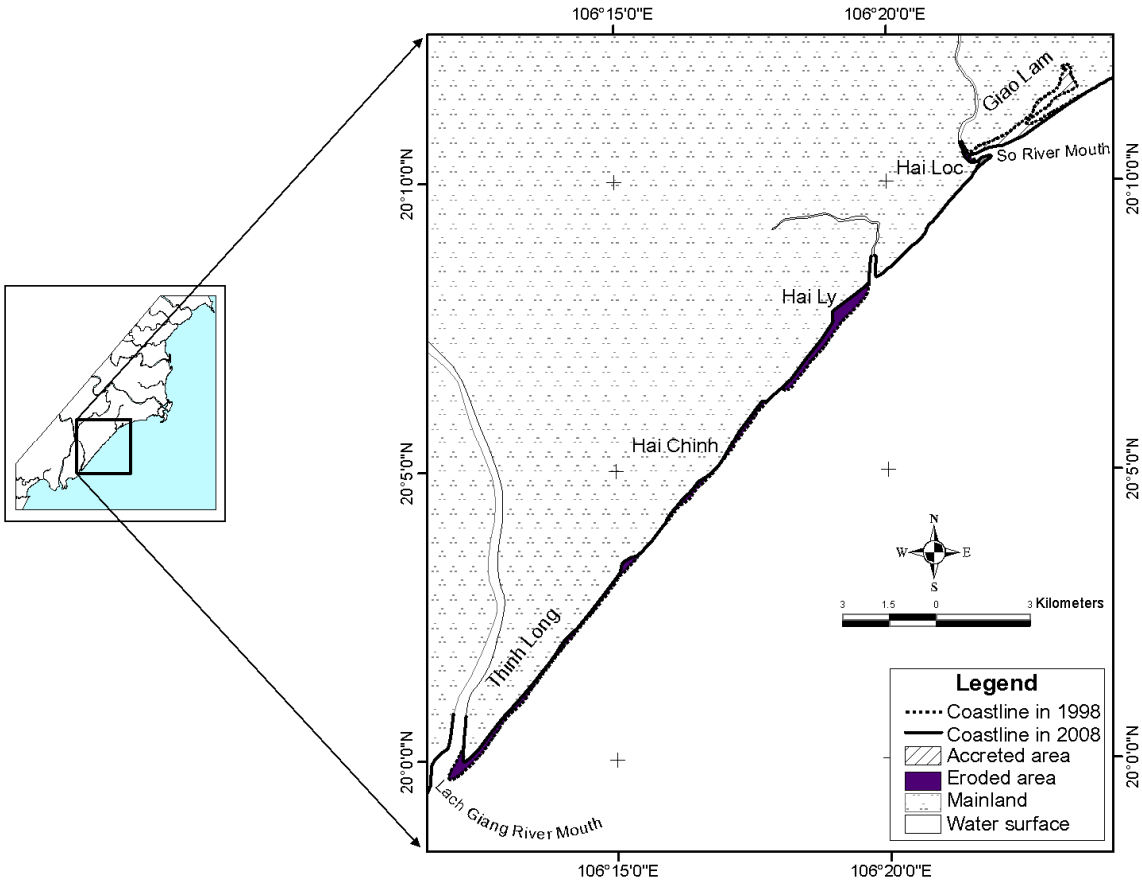

Figure 3. Map of erosion/accretion of So - Lach Giang coastal zone in 1998 - 2008

Lach Giang - Lach Truong coastal area

Accretion was very strong both in intensity and scale along the Lach Giang - Lach Truong coastal area from 1998 to 2008 (figure 4). The total accreted area extends about 2,828ha along a 46.2km long coastline at an average rate of about 37.5m per year (table 4). Three coastal segments were also eroded at the Nghia Phuc and Rang Dong Commune of Nghia Hung District, Nam Dinh Province and one at the Hau Loc Commune of Ngu Loc District, Thanh Hoa Province with a strong intensity and a large scale. The total eroded area was about 133ha along an 11.3km coastline at an average rate of 10.1m per year (figure 4).

Table 4. Erosion/accretion in the Lach Giang - Lach Truong coastal area in 1998 - 2008

Province	*District*	*Commune*	*Area (ha)*	*Length (m)*	*Rate (m/year)*	*Intensity*	*Scale*
Nam Dinh	Nghia Hung	Nghia Phuc	9.28	1,379	- 6.5	Strong	Medium
			8.05	1,481	+ 5.4	Medium	Medium
		Rang Dong	2,114.60	23,436	+ 90.2	Very strong	Very large
			28.55	2,572	- 11.2	Very strong	Large
Ninh Binh	Kim Son	Binh Minh	517.60	15,406	+ 33.7	Very strong	Very large
	Nga Son	Nga Thuy	139.94	3,384	+ 41.2	Very strong	Medium
Thanh Hoa	Hau Loc	Da Loc	47.70	2,801	+ 17.0	Strong	Medium
		Ngu Loc	95.15	7,360	- 12.8	Very strong	Very large

Note: - is erosion, + is accretion

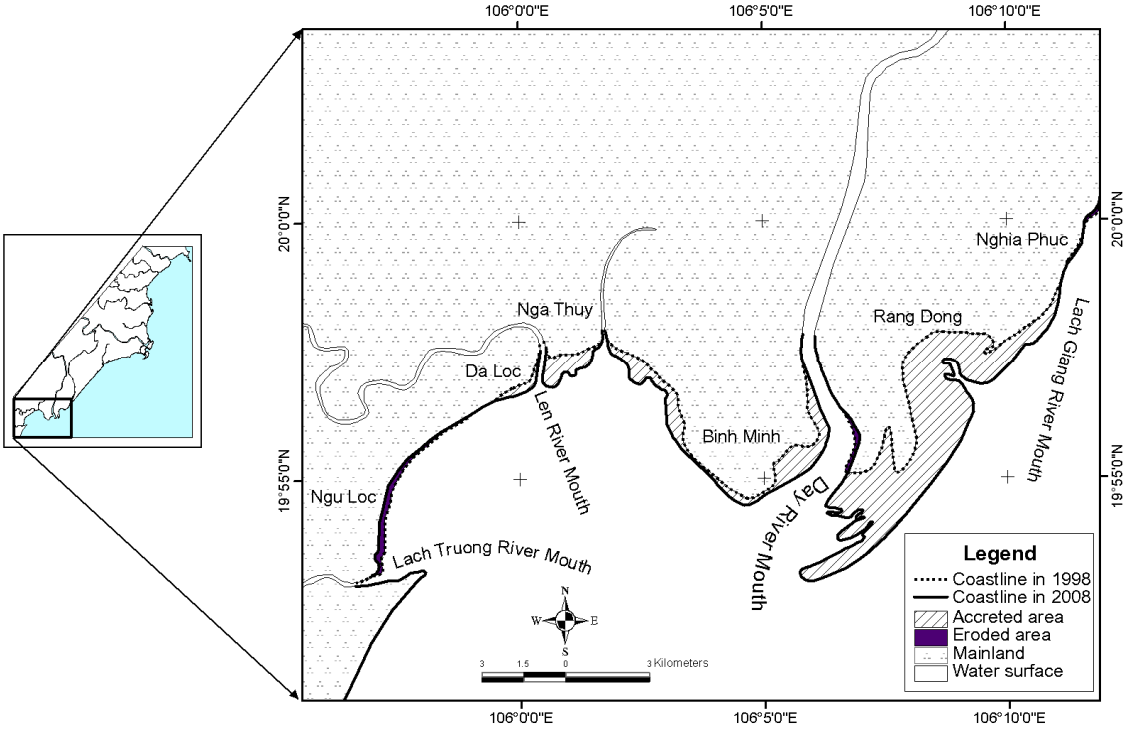

Figure 4. Map of erosion/accretion of Lach Giang - Lach Truong coastal zone in 1998 - 2008

DISCUSSION

Coastline change in the Red River Delta in 1998 - 2008

Coastal accretion in 1998 - 2008 dominated the coastal areas of the Kien Thuy, Tien Lang, Thai Thuy, Tien Hai, Nghia Hung and Kim Son Districts with a very strong scale and intensity. The total accreted area in this southern section of the Red River Delta was about 10,256ha along a 172km long coastline at an average rate of 34m per year. Compared to the other periods [3], the scale of accretion during the 1998 to 2008 period has doubled (table 4).

The coastal area from the Kien Thuy District to the northern part of the Thai Thuy District was with accretion rates of 60m to 80m per year recorded in the areas surrounding the Van Uc and Thai Binh river mouths. Sedimentation in this area was occurring symetrically along the coastlines between these river mouths suggesting that longshore currents were not strongly influencing coastline change.

The northern part of the Tra Ly river mouth was under erosion at the offshore sandy floor, but the coastline was moving seaward. The Ba Lat river mouth area showed a complex history of coastline change with minor zones of erosion, on the eastern shore and within the estuary at Con Vanh and the eastern shore at Con Lu. Very strong intensity and scale of accretion were within the Ba Lat river mouth and to the north and south of it. Dien et al. [3] showed that parts of this river mouth were accreting at rates of 100m per year in period from 1990 to 1998, and in this study it is indicated that the rate keeps continuing.

Asymmetric accretion was occurring in the Day river mouth with the north-eastern shore at a rate (90m per year) that was approximately three times faster than that in the south-western shore (34m per year). Dien et al. [3] showed that parts of this coastline were on average accreting at rates of about 100m per year in 1990 - 1998. This asymmetry may be due to the accumulation of sediments from Dai Giang River transported south by longshore drift and deposited on the northern shore of the Day river mouth.

In the coastal zone from Do Son to Lach Truong, two coastal sections were in strong erosion in 1998 - 2008, including the Hai Hau coast and the Hau Loc coast.

Dien et al. [3] showed that the Hai Hau coast was eroded in parts since at least 1930 at a rate of 5 to 10m per year. Between 1990 and 1998, the local government built a series of dykes using unconsolidated rocks along the coastline embankment in an effort to reduce erosion. The coastal section from Hai Chinh to Thinh Long on the Hai Hau coast was eroded at a high rate, reaching 20 to 30m per year at some sites [3]. During the period from 1998 to 2008, this area continued to be eroded at a rate of 11m per year, with some of the coastal sections, such as at Thinh Long and Hai Ly, being eroded at a rate of over 20m per year. In the future, it is predicted that this coast will continue to be eroded even though dykes have been built along the coast.

The erosion of the Hau Loc coast has persisted since 1930. From 1990 to 1998, it occurred with a stronger intensity and larger scale in comparison with previous periods [3]. Although this coast has had unconsolidated stone dykes built, the erosion has continued in this period at an average rate of 10m per year. In the Ngu Loc coastal section, the rate of erosion was most intensive, reaching 20m per year in this period. During 1998 to 2008, the Hau Loc coast was eroded at a rate of over 10m per year along an 11.3km coastline. In the future, this coastline will continue to be eroded, although this coast has had stone dykes constructed.

Erosion along the Hai Hau and Hau Loc coastlines can be attributed to the prevalent southwestward longshore currents at depths of less than 5m and southward currents between 10 and 30m depth [4]. Duc et al. [4] described the Hai Hau coastline as behaving like a "high-wave energy coast" (p. 564), and the continued high rates of erosion, similar oceanic current systems and the geomorphology of the Hau Loc coastline indicates a similar environment.

Table 5. Coastline change in the Red River Delta in different periods

Coastal part	1930 to 1965		1965 to 1990		1990 to 1998		1998 to 2008		Status
	Rate (m/y)	Length (m)	Rate (m/y)	Length (m)	Rate (m/y)	Length (m)	Rate (m/y)	Length (m)	
Do Son to Tra Ly	9.2	25,120	9.1	19,070	7.5	1,800	10.7	5,858	Erosion
	21.8	24,600	41.2	27,700	27.1	33,400	50	54,000	Accretion
Ba Lat river mouth	11.3	9,500	15.4	9,300	0	0	11.6	5,780	Erosion
	38.7	28,400	55.4	31,200	24.4	12,300	36.3	64,000	Accretion
So to Lach Giang	4.6	8,600	9.6	19,500	15.6	17,200	11	20,300	Erosion
	13.9	4,200	2.5	4,100	0	0	14	7,835	Accretion
Lach Giang to Lach Truong	10	2,160	8.1	7,100	15.6	5,500	10.1	11,300	Erosion
	56.1	32,600	59	34,000	>100	29,100	37.5	46,000	Accretion
Whole area	***8.7***	***45,380***	***10.5***	***54,970***	***12.9***	***24,500***	***10.1***	***43,200***	***Erosion***
	32.6	***89,800***	***39.5***	***97,000***	***>37.8***	***74,800***	***34***	***171,835***	***Accretion***
References			Dien et al. [3]				This study		

Causes of coastline change in the Red River Delta

Natural causes

The coastline change in the Red River Delta coastal area is complex in scale and intensity, highly dependent on the geomorphologic characteristics of each coastal section, riverine and oceanic dynamics. Dien et al. [3] found that in this coastal area, sites near river mouths are undergoing accretion and ones distant from major river mouths are undergoing erosion. The same broad pattern is apparent from the present study.

Thanh et al. [9] showed that where tectonic subsidence of the coastal and offshore region of the Red River Delta is accompanied by sediment deposition from river mouths, deltaic accretion occurs. At sites distant from river mouths, the tectonic subsidence and the resultant eustatic sea level rise and longshore oceanic currents results in the erosion of the coastal zone. In Red River Delta, the tectonic subsidence is dominating, but the accretion is still strong, thank to the high rate of compensative deposition. In a certain condition of locally deficient sediments, the total subsidence of both tectonic sink and eustatic rise of sea level

become the cause of coastal erosion. The lack of sediments in coastal zone and estuaries in the present time mainly concerns the water uses in the catchment, for example damming and irrigation. This can be demonstrated by influence of Hoa Binh Dam on the upstream of Red River. The construction of the Dam was completed in 1989 and every year, the volume of some 40 million sediments accounting for 40 percent of total sediment discharge of Red Rive are trapped in the reservoir bottom [9]. However, the direct cause of coastal erosion belongs to the meteoro-hydrology factors such as the actions of wave, current, typhoon, and sea level rise, including monsoon and storm surges. Recently, the turbulence of these factors by the global warming has caused unusually coastal erosion. The observed data in some stations show the sea level rise of 2-3mm/year in Red River Delta [9].

Some extensive studies of the sedimentation and water dynamics of the Ba Lat Estuary [9, 12, 13, 14] in 2005 - 2007 showed a complex interplay between the tidal regime, seasonal and extreme climatic events, and the velocity and bedload of the river plume were the dominant features controlling the morphology of the estuary. In particular, the avulsion of the former Ba Lat channel in 1971, 10km to the south, has had a major influence on the sedimentation in this estuary with increased rates of accretion at the site of the present river mouth and low rates of accretion and erosion near the former river mouth.

Human activities

During 1992 to 2008 period, one of the main causes of the increase in scale and intensity of the accretion is due to human activities to exploit directly resources in the coastal wetland area. For example, between 1992 and 2002, the area converted to aquaculture ponds in the Xuan Thuy and Tien Hai region was increased by factors of 9 and 5, respectively [7]. The 1992 to 2002 period also recorded an increase in the area of mangrove plantation in the Xuan Thuy and Tien Hai regions with the increases of 7km^2 in each region [7]. Thao [11] reported that over 3,000ha of aquaculture ponds were established and about 2,500ha of mangroves were planted in the tidal flat areas of this section of the Red River Delta coastal zone between 1998 and 2008. Aquaculture ponds and mangrove plantations help stabilize sedimentation in coastal zones by minimizing remobilization of the sediment. Thus, with continued development of aquaculture ponds and plantation of mangroves along these accreted shorelines, there is strong evidence to suggest that the rates of accretion in these regions will continue at the present rates.

It is still unclear that human activities such as construction of channels, dykes and dams have impacted on the coastline change [4], although Seto and Fragkias [7] and Thao [11] showed that aquaculture pond development and plantation of mangroves could facilitate coastline accretion. Thanh et al. [9] indicated that a range of human activities, such as river damming, irrigation practices, dyke building, river channel dredging, mangrove destruction and mining practices, would played a significant role in the observed coastline changes. The data presented here suggest that the construction of unconsolidated stone dykes in the Hai Hau and Hau Loc coastal zones has not impacted upon the erosion rates in these areas.

From Dien et al. [3] and the results of the study, it is clear that the processes causing the erosion and accretion are continuing to affect the coastline morphology in the Red River Delta.

CONCLUSION

Remotely sensed data has been used to monitor coastline change in Red River Delta in period from 1998 to 2008. The results of coastline change assessment show that the coastline change has occurred in a complicated manner. The scale and intensity of accretion in this period were higher than previous periods with about 10,256ha accreted along a 172km long coastline and at an average rate of 34m per year. Erosion has also occurred in some regions of the Red River Delta, at a scale and intensity smaller than previous periods. The total eroded area was about 542ha along a 43.2km coastline at an average rate of 10.1m per year.

Remote sensing data and GIS technologies have presented useful information on the coastal erosion of the Red River Delta. In this study, the coast was defined as the mean sea level and mud-sandy coasts where tidal dynamics dominated, and as the high sea level on sandy coasts where wave dynamics dominated. Regular monitoring coastal erosion by remote sensing and GIS is an important tool that needs to be utilized for better management of the coastal environment.

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GIÁM SÁT BIẾN ĐỘNG BỜ BIỂN CHÂU THỔ SÔNG HỒNG SỬ DỤNG DỮ LIỆU VIỄN THÁM

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TÓM TẮT: *Nghiên cứu này sử dụng dữ liệu viễn thám để giám sát biến động bờ biển châu thổ sông Hồng từ năm 1998 đến 2008. Để xử lý dữ liệu ảnh vệ tinh, đường bờ biển được các định trùng mực biển trung bình trên đới bờ bùn cát nơi thủy triều là yếu tố động lực thống trị và mực biển cao trên đới bờ cát nơi sóng là yếu tố động lực thống trị. Công cụ GIS được sử dụng để phân tích định lượng thay đổi đường bờ biển. Kết quả nghiên cứu chỉ ra rằng, đường bờ biển châu thổ sông Hồng thay đổi phức tạp trong suốt 10 năm qua, khoảng 10.256ha đã được bồi tụ và xói lở khoảng 542ha. Bờ biển khu vực Hải Hậu và Hộc Lộc xói lở diễn ra với qui mô lớn và cường độ rất mạnh. Ở các đoạn bờ khác của châu thổ sông Hồng, xu thế bồi tụ là thống trị với tốc độ trên 30m/năm. Các vùng xói lở và bồi tụ là địa chỉ quan trong trong quản lý đới bờ ở châu thổ sông Hồng.*

Từ khóa: *Châu thổ sông Hồng, xói lở, bồi tụ, quản lý đới bờ biển, viễn thám, hệ thông tin địa lý.*