

ABSTRACT

LU, CHI. Natural and Human Impacts on Recent Development of Yangtze River and Mekong River Deltas. (Under the direction of Dr. Paul Liu).

The Yangtze River Delta is the largest delta in China and is also a highly populated delta where metropolitan cities such as Shanghai are located. The evolution of Yangtze River Delta will directly influence the economics and environment in this area. The sediment flux from Yangtze into the delta decreased during the past three decades and the operation of world's largest hydropower project, Three Gorges Dam, made this situation much more severe. In the delta area, another large project called Deep Water Navigation Channel was also completed in recent years. Mekong River Delta is another major delta in Asia and also has a lot of dams in the river basin.

To document the relationship between human impacts on the large river basin and coastal evolution, in this study, we used Jiuduan Island of Yangtze River Delta and two islands of Mekong River Delta as examples and utilized Landsat data to show how these island's shoreline changed with the trend of decreased sediment discharge. In Mekong River Delta, the shoreline change agreed well with the sediment flux, eroding from 1989 to 1996 and prograding from 1996 to 2002. In Yangtze River Delta, shoreline kept growing before Three Gorges Dams was operating, eroded from 2003 to 2009 and then prograded again from 2011 to 2013. The main reason for the shoreline progradation from 2011 to 2013 was the impact of the Deep Water Navigation Channel project which totally changed the sediment transport process around Jiuduan Island.

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Natural and Human Impacts on Recent Development of Yangtze River and Mekong River
Deltas

by
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BIOGRAPHY

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1. Introduction

River deltas accumulate deposition of terrigenous sediment where rivers enter into the sea. If rivers deliver sufficient sediment, the deltaic coastline will keep prograding. However, due to the natural processes and human activities, sediment loads from many rivers have been reduced over the past century and most of these river deltas are now in destruction phases (Syvitski et al., 2009). Examples such as Nile River Delta which was a former depocenter has been changed to a coastal plain dominated by subsidence and erosion due to water regulation (Stanley and Warne, 1998); Due to the dramatic decrease of the sediment load from Danube River Basin, it is insufficient for supporting Danube River Delta progradation (Giosan et al., 2013); Anthropogenic impacts such as water-soil conservation practices and reservoir construction caused large reduction of sediment load from the Yellow River Basin and the increased erosion rate of Yellow River Delta (Peng et al., 2010).

Among human activities, dam constructions are the main reason for the decreased sediment load. Yangtze River is a world major river where a lot of dams were built in its river basin (Yang et al., 2011), including the world's present largest dam Three Gorges Dam which was closed in 2003(**Fig.1**). Dam constructions have already been a significant factor of the decreased sediment loads. Previously, the annual sediment load of Yangtze River was about 480 Mt/yr (Milliman and Meade, 1983). After the closure of Three Gorges Dam, this number decreased to less than 200Mt/yr.

Although the Yangtze River sediment load is decreased, however, different from other major river deltas such Yellow River Delta and Nile River Delta which are in rapid erosion phases, whether Yangtze River Delta is in an erosion or accretion phase is still a controversial issue. In response to the reduced sediment input, Yangtze subaqueous delta began to erode in recent years. (Gao et al., 2011; Yang et al., 2011). However, the subaerial delta still experienced progradation (Chu et al., 2013).

In addition to the decreased sediment load from Yangtze River Basin, coastal engineering is another factor influencing the sediment transport and morphodynamic changes of Yangtze River Delta (Dai et al., 2013). Among all the engineering constructions, an engineering project called the Deepwater Navigation Channel is the largest one. It started in 1998 and was completed in 2011 (**Fig.2**), creating a 92 km long channel with a water depth of 12.5 m below the mean lowest low water. The length of the two dikes is 48.1 km to the south of the channel and 49.2 km to the north and the total length of the 19 groins is 30 km. They were constructed to increase current speed and decrease sediment deposition in the channel (Song et al., 2013). In the lower reaches of Yangtze River, the river channel sequentially bifurcates at four islands, Chongming, Hengsha, Changxing and Jiuduansha island (**Fig.3**). The north jetty was built on the south side of Hengsha Island and the south jetty was built on the north side of Jiuduan Island. Fundamental morphological evolution simulation based on Delft3D model has been set up for Jiuduan Island due to human intervention(Hu et al., 2009).

Natural factors also have an influence on the morphological changes of Yangtze River Delta shoreline. Due to the Sea level rise and coastal land subsidence, the sea level rises at a rate about 5.44mm/yr at Yangtze estuary (Zhou et al., 2013). With the rising sea level, morphological changes such as beach erosion will be affected. Waves especially during typhoons will be a major role in changing the tidal flat morphology in a small scale and over a short time period(Fan et al., 2006). These natural factors are significant in erosion and progradation of deltaic shoreline.

In Mekong River basin, dam and reservoir constructions has also been very fast recently (**Fig.4**). However, whether these dams, such as Manwan dam in upper Mekong River, have a great influence on the sediment flux downstream is still controversial. Sediment load near the dam sites was reduced sharply(Kummu and Varis, 2007; Lu and Siew, 2006), but in the lower Mekong River the sediment load change related to the dam construction was not very significant (Walling, 2008). The estimated annual sediment flux into the ocean can still reach the level of 160 million tons (Milliman and Meade, 1983).

In Mekong River Delta, the river mouth is bifurcated and sand bars are also developed there (Tamura et al., 2012). Compared with the islands in Yangtze River Delta, these sand bars in Mekong River Delta have not been manipulated by major coastal engineering projects (**Fig.5**). The land is mostly used to agriculture aquaculture and forestry. A large part of the area experiences seasonal floods, peaking in from September to October and lasting until the beginning of December which will bring large amounts of sediment (Bouvet and Le Toan, 2011). In contrast with the subsurface sedimentary study of the delta

and coastal area (Lap Nguyen et al., 2000; Xue et al., 2010), the shoreline change of Mekong River Delta has not been fully studied.

This paper will focus on whether Jiudian Island in Yangtze River Delta experienced erosion or deposition due to the combined effect of decreased sediment load from Yangtze River basin and the Deep Water Navigation Channel project and make a comparison between the shoreline change of Jiudian Island and the shoreline changes of the islands in Mekong River Delta.

1.1 Study area

The Yangtze River originates from the Qinghai-Tibetan Plateau, flowing into East China Sea. Among Asian rivers, it is the largest river in term of water discharge (Milliman and Meade, 1983). The modern Yangtze River discharges most of its annual sediment load between June and September (Chen and Stanley, 1993). Yangtze estuary where Jiudian Island is located is a mesotidal estuary. The tide in Yangtze estuary is mainly semi-diurnal tide, the mean tide range and the spring tide are about 2.66m and 5m respectively and the flow velocity is about 1m/s (Gao et al., 2011; Jiang et al., 2012). The mean and maximum wave heights are 1.0m and 6.2m respectively (Fan et al., 2006). The local semi-diurnal tidal cycles has been strongly affected the dispersal pattern of the Yangtze derived sediment (Liu et al., 2007). The Holocene Yangtze delta covers an area of about 52,000 km², with 23,000 km² subaerial delta and 29,000 km² subaqueous delta (Li et al., 1986). The topography of the Yangtze delta plain is characterized mainly by an elevation of about 2 m above mean sea

level in the central delta plain (Chen and Wang, 1999). After reach its mid-Holocene highstand about 7000 years ago, the modern Yangtze Delta began to accrete (Chen and Stanley, 1993; Li et al., 2000a; Stanley and Warne, 1994). Over the past 3000 yrs the high sea level gradually retreated, reaching its present level (Zhao et al., 1994). During this time, fluvial sediments accumulated along the periphery of the delta plain (Stanley and Chen, 1996).

The accumulation of the sediment from Yangtze River Basin formed the four islands at the river mouth (Yang et al., 2000). In 1954, a flood event which was the largest documented flood in Yangtze River Basin caused the current distribution of the islands in Yangtze estuary (Shen et al., 2013). Among these four islands, Chongming Island, Hengsha Island, and Changxing Island are inhabited and Jiuduan Island is a younger and uninhabited island. **(Fig.3)** Jiuduan Island is a national nature reserve of wetland. Marsh vegetation such as *Scirpus mariquete* and *Scirpus triquier* are planted on the island and the boundary between the bare flats and the marsh is located about 50cm about the mean sea level (Yang et al., 2000).

Mekong River also originates in the Tibetan Plateau, flows through China, Myanmar, Thailand, Lao PDR, Cambodia, and finally enters the South China Sea in southern Vietnam. The total length of the Mekong River is about 4750 km. Annual water discharge of the Mekong River is 470 km^3 and the estimated annual sediment flux is 160 million tons (Milliman and Syvitski, 1992). The Mekong River Delta covers an area of $49,500 \text{ km}^2$ (Le et al., 2007). The delta plain is the third largest in the world (Coleman and Roberts, 1989), 50%

greater than the Yangtze delta. The Mekong River delta coast is a mesotidal area with moderate wave energy. The tide is semi-diurnal with mesotidal range 3.5m along the South China Sea coast, while tides on the Gulf of Thailand coast are diurnal with a microtidal range about 0.8-1.0m (Tamura et al., 2010; Xue et al., 2010). The mean wave height is 1.5m. The study area in this paper is located along the South China Sea coast, so the tidal range and mean wave height are similar to those in Yangtze River Delta. In lower Mekong, the climate is humid and tropical(Xue et al., 2011). Wet (summer) and dry (winter) seasons are clearly distinguished as a result of the monsoons. The average maximum daily discharge from 1924 to 2006 in Kratie in summer is about ten times the average daily discharge in winter (Tamura et al., 2010).

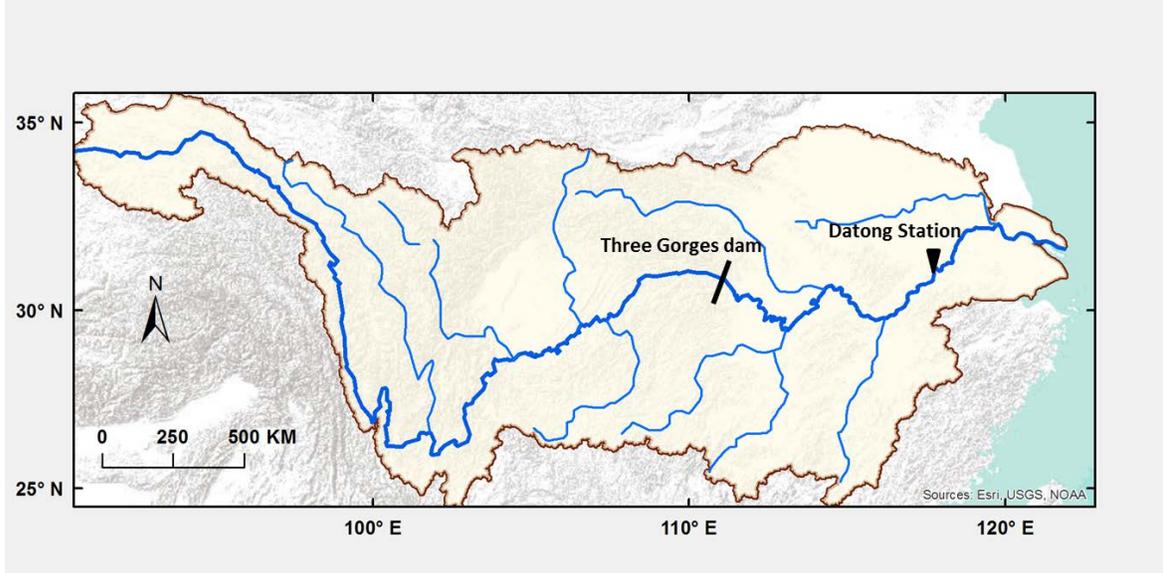


Fig.1 Yangtze River Basin and location of Three Gorges Dam and Datong station

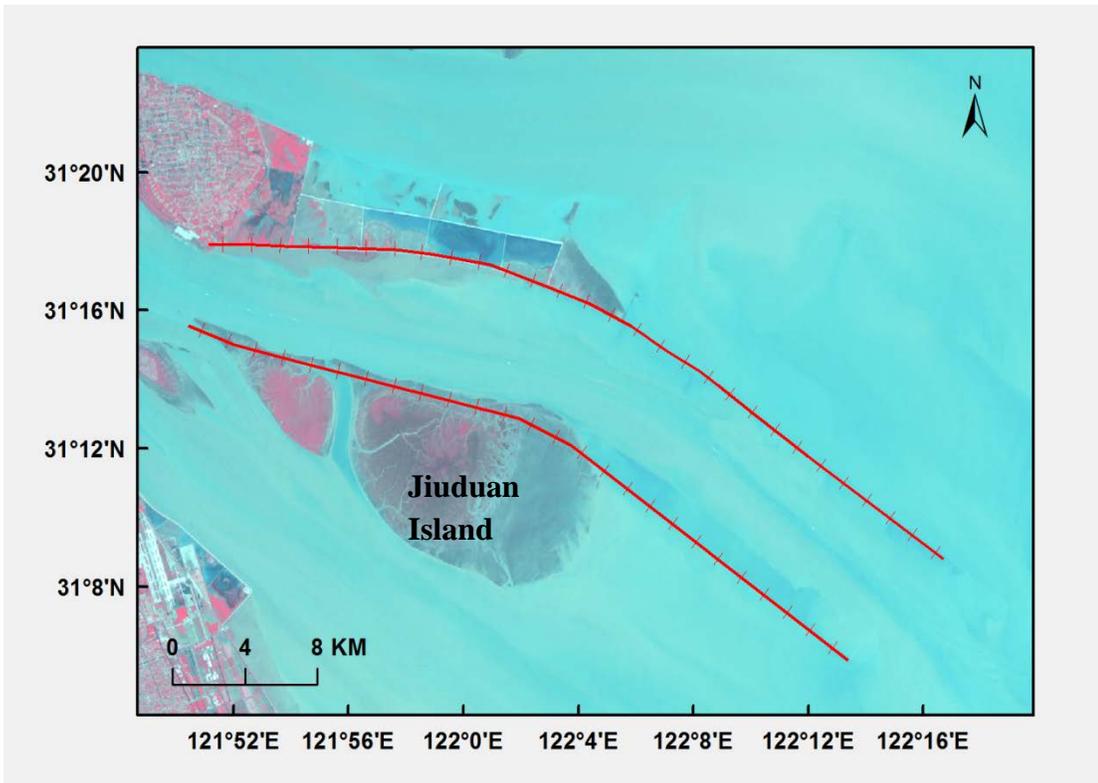


Fig.2 Deep Water Navigation Channel and location of Jiuduan Island

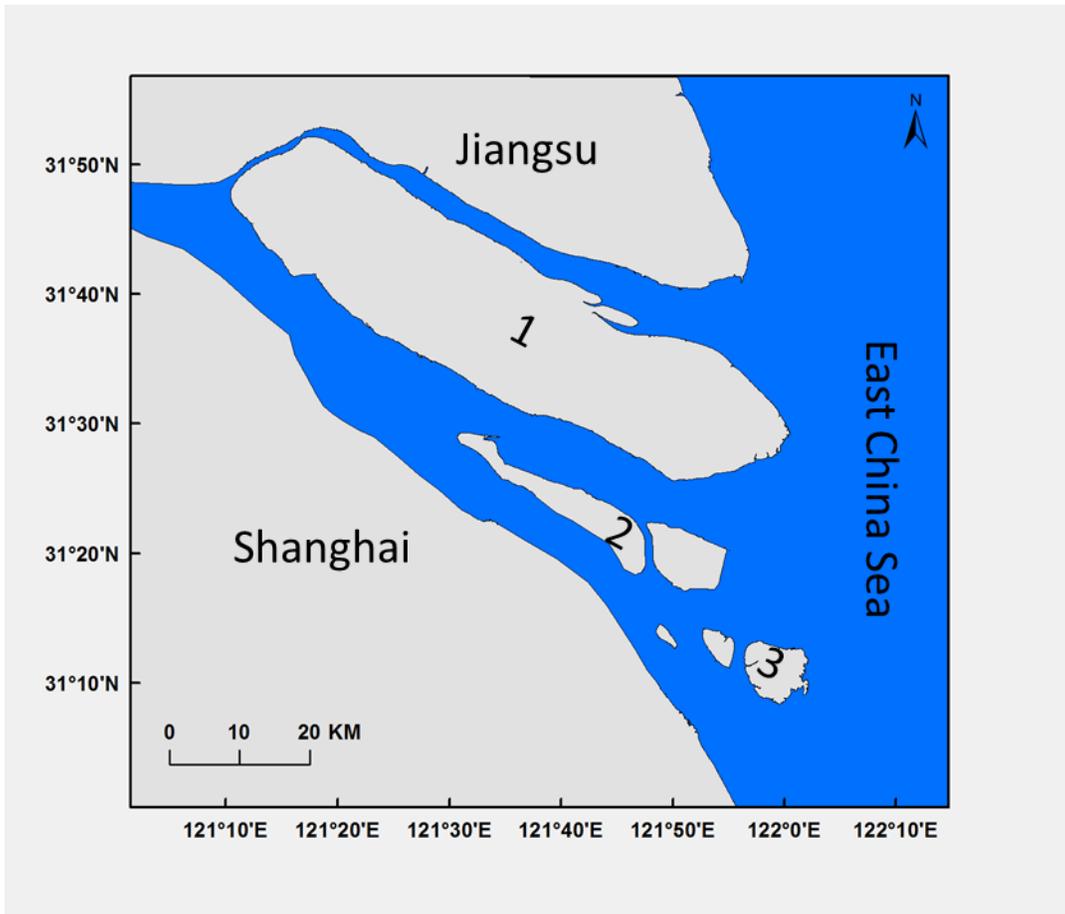


Fig.3 Yangtze River Delta

(1 Chongming island 2 Changxing and Hengsha island 3 Jiuduan island)

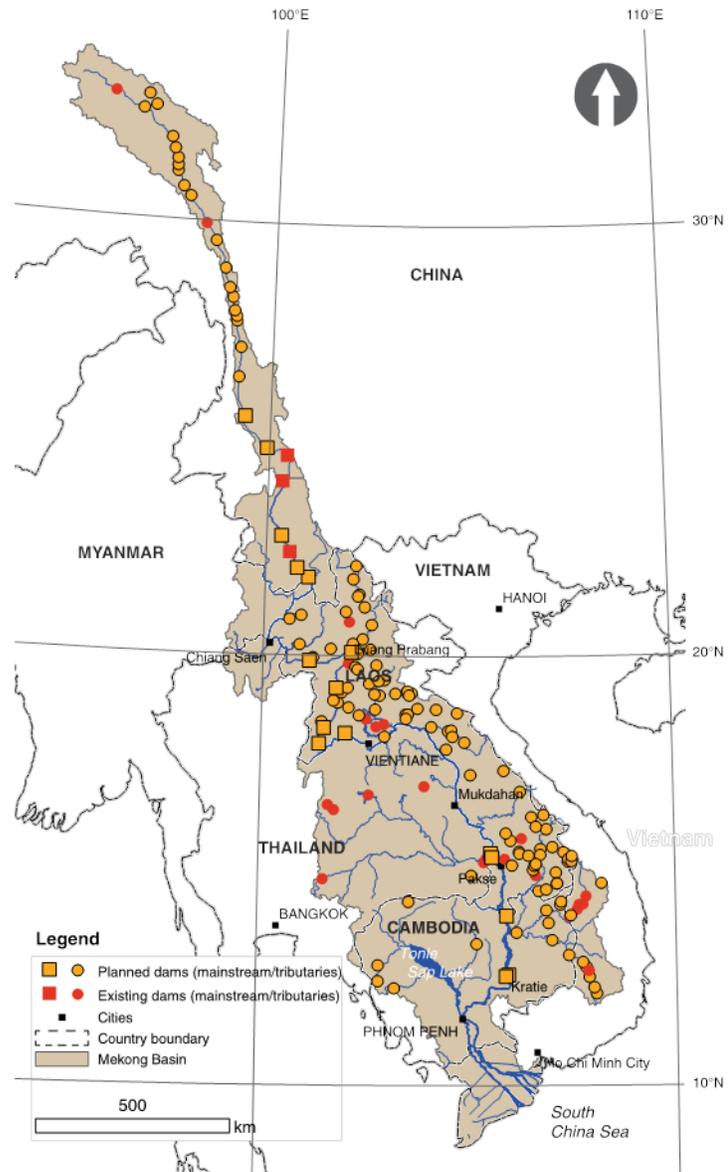


Fig.4 Mekong River Basin and dam locations

(From Johnston and Kumm (2012))

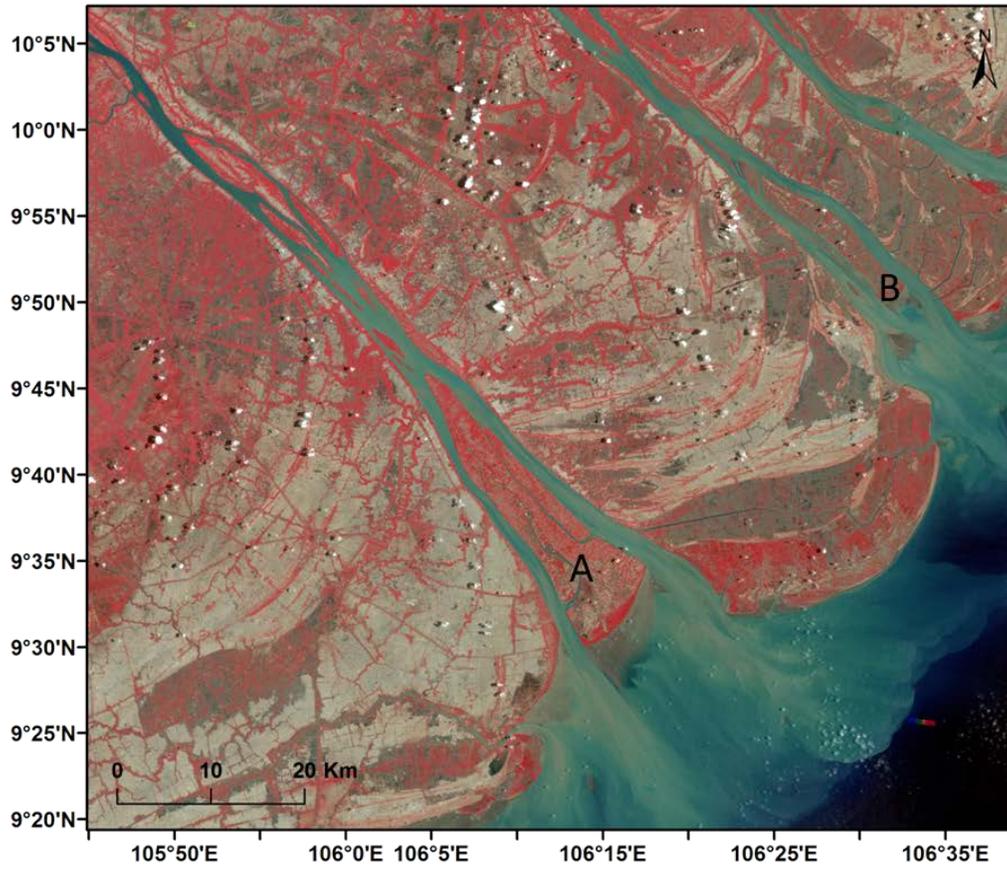


Fig.5 Mekong River Delta and the two islands analyzed in this study

(A: Cù Lao Dung, B: Hòa Minh)

2. Material and methods

2.1 Data source

Annual water and suspended sediment discharges between the 1950 and 2012 at Datong gauging station were collected from Yangtze Water Resources Commission. Annual water and suspended sediment discharges between the 1960 and 2003 at Khong Chiam gauging station were digitalized from Wang et al. (2011b).

In order to investigate the shoreline changes in Jiudian Island, a time series of Landsat images are downloaded and used which are available from USGS Website (<http://glovis.usgs.gov/>).

The data used in the study are Landsat 5 and Landsat 7 images with a 30-m spatial resolution. Landsat 5's sensor is Landsat Thematic Mapper(TM) and Landsat 7's sensor is Landsat Enhanced Thematic Mapper Plus (ETM+). All of the data used in this study are Level 1T (L1T) data product. The Level 1T (L1T) data product provides systematic radiometric accuracy, geometric accuracy by incorporating ground control points, while also employing a Digital Elevation Model (DEM) for topographic accuracy. It should be noted that an instrument malfunction occurred onboard Landsat 7 on May 31, 2003. The problem was caused by failure of the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite. Subsequent efforts to recover the SLC have not been successful, and the problem is permanent. So after May 31 2003, Landsat 7 ETM+ continued to acquire image data in the "SLC-off" mode.

The path and row of these images are 118 and 38 respectively, which can cover the interested study area. These Landsat TM/ETM+ images are selected based on two requirements: 1) the image has little or no cloud coverage so the image can be seen clearly; 2) the tide levels of these images at their acquisition time are similar and at low tide levels, so that more of the tidal flat can be exposed in the air. The tide levels were determined by the tide prediction chart at WuSong Gauge Station which is near the study area Jiudian Island. In the end, satellite images from 1987 to 2013 were selected and their basic information was listed in **Table 1**.

Table1 Information of the satellite images used in this paper

Satellite	Date	Time (GMT)	Time (CST)	Tide level (cm)
Yangtze River				
LANDSAT_5 TM	12/14/1988	1:55	9:55	90
LANDSAT_5 TM	1/26/1993	1:46	9:46	70
LANDSAT_5 TM	4/24/1996	1:35	9:35	140
LANDSAT_5 TM	12/29/1999	2:00	10:00	150
LANDSAT_7 ETM+	3/13/2001	2:15	10:15	30
LANDSAT_5 TM	1/3/2002	2:04	10:04	70
LANDSAT_7 ETM+	1/3/2005	2:14	10:14	100
LANDSAT_7 ETM+	1/9/2007	2:15	10:15	90
LANDSAT_7 ETM+	1/14/2009	2:14	10:14	50
LANDSAT_7 ETM+	4/26/2011	2:18	10:18	200
LANDSAT_7 ETM+	4/28/2012	2:19	10:19	140
LANDSAT_7 ETM+	5/1/2013	2:21	10:21	100
Mekong River				
LANDSAT_5 TM	4/6/1989	2:43	9:43	160
LANDSAT_5 TM	2/21/1996	2:19	9:19	80
LANDSAT_7 ETM+	2/13/2002	3:02	10:02	90

2.2 Image corrections

Landsat images were analyzed using software ArcGIS. After radiometric, geometric and terrain correction, Landsat 7 ETM+ scan line errors caused by "SLC-off" were corrected by filling the gap using the nibble demand.

After correcting the scan line errors, band combinations were applied for both Landsat5 and Landsat7 images. Here, we combined band 4, band 3 and band 2 to create the new RGB image since this included the near infrared channel (band 4), and land water boundaries were clearer which would make it easier to identify the shoreline.

2.3 Shoreline extraction

The shoreline was firstly extracted by Landsat toolbox (Daniels, 2012) and then was modified manually according to the knowledge about morphological features and sediment characteristics (Color, sediment type and water content) of the coastline.

The shoreline change rates were calculated using Digital Shoreline Analysis System (DSAS) version 4.3, an ArcGIS extension for calculating shoreline change developed by USGS (Thieler et. al. 2009). The workflow by using DSAS application is shown in **Fig.6**.

Because the shoreline in my study area was always non-straight and very complex, here we used the area change rate, the End Point Rate (EPR) to represent the shoreline change rate. The area change rate is the change of Jiudian Island area per year. The end

point rate is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline.

$$EPR = \frac{\text{distance}(m)}{\text{time between oldest and most recent shoreline}(yr)}$$

The major advantages of the EPR are the ease of computation and minimal requirement of only two shoreline dates. The major disadvantage is that if there are more data available, the additional information such as changes from accretion to erosion, magnitude, or cyclical trends may be ignored. Therefore, when we focused on a shorter time period here such as only using three shorelines, the End Point Rate would be used since there will be less additional information such as the cyclical trends.

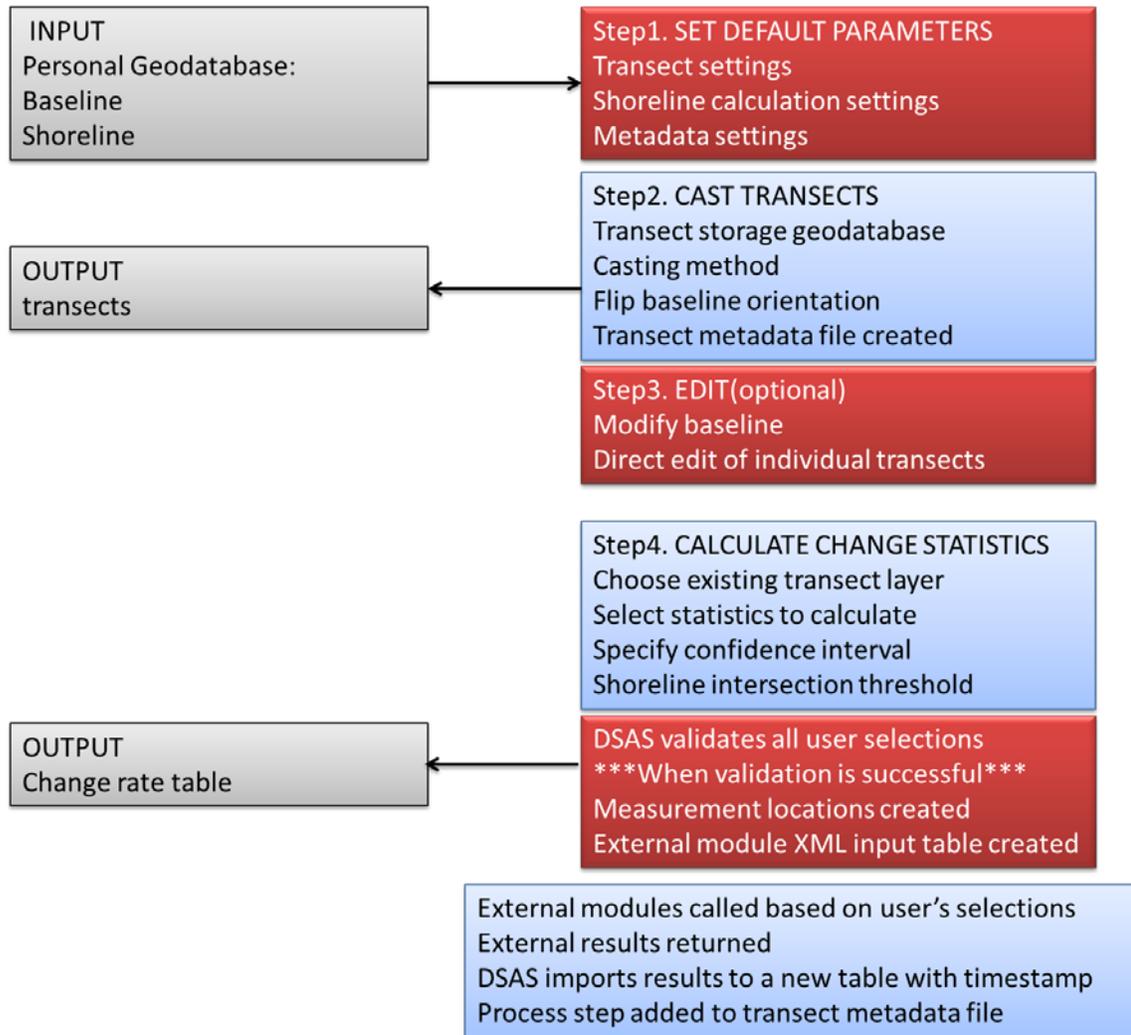


Fig.6 Digital Shoreline Analysis System work flow

3. Results

3.1 Water and sediment discharge

Yangtze River annual runoff and sediment discharge at Datong station are shown in (Fig.7) From (Fig.7), it can be seen that the annual runoff before and after the Three Gorge Dam operation did not change too much. Although there were some fluctuations in different years' annual water discharge, the annual water discharge could still maintain a level of about 1000 km³/yr. The fluctuations were mainly determined by the differences in precipitations of different years. For example, in 1998 and 2010, there were big flooding events in Yangtze River Basin, so the annual water discharges were also very high. Severe drought occurred in 2006, so the annual runoff was much lower. Generally, the annual water discharge of Yangtze River did not show an obvious decreasing trend after the operation of Three Gorges Dam operation in 2003.

Compared to the annual water discharge, the annual sediment discharge dropped a lot after the operation of Three Gorges Dam. Before 2003, the annual sediment discharge could reach the level of about 500Mt/yr. However, after the operation of Three Gorges Dam, the average number decreased to about 150Mt/yr. So although annual water discharge did not change a lot between pre-dam and post-dam periods, annual sediment discharge had a great reduction after the operation of Three Gorges Dam.

The sediment measurements in the lower Mekong river basin were scarce and discontinuous. Generally, the sediment discharge was consistent with the water discharge (Fig.8). The average sediment load value in this period was 145Mt/yr. The sediment load

showed a significant increase from 1985–1991 and then sharply decreased from 1991 to 1992. After Manwan dam began operation in 1992, the sediment load increased from 1992 to 1994 and then decreased in 1995.

3.2 Jiudian Island Shoreline change

From 1988 to 2013, Jiudian Island grew from several separated small islands into a larger island and the shoreline mostly moved towards seawater (**Table2**). During 1988–2013, the area of the study area increased from 27.63km² to 114.25km². The progradation rates of the four time periods were 5.06 km²/yr (1988–1996), 9.22 km²/yr (1999–2002), -0.78 km²/yr (2005–2009) and 10.88 km²/yr (2011–2013) respectively. These results indicated that the Jiudian Island kept growing before Three Gorges Dam operation and this progradation rate was much higher after 1998 when Deep Water Navigation Channel project started building. After 2003, this rate slowed down and the shoreline changed from deposition to erosion. However, after the Deep Water Navigation Channel project was completely finished in 2009 and a new groin was built near the south jetty, the shoreline remained to advance into the sea with the largest progradation rate among all the time periods.

Before 1998, there were no human impacts on the evolution of Jiudian Island. The average progradation rate was 5.06 km²/yr. In 1988, Jiudian Island was still split into different parts and the total area was about 27.63km². Then the upper part of the sand body was transported towards the southeast direction and finally attached to the lower part. From 1988 to 1996, the island grew and extended in all directions from several separated smaller

sand bodies into a much larger island, especially in the southeast direction, which increased the total area to 64.95km² in 1996(**Fig.9**).

Table2 Area of Jiudian Island and area change rate

Time	Area of island(km²)	Change rate(km²/yr)
2011-2013		10.88
5/1/2013	114.25	
4/28/2012	103.28	
4/26/2011	92.32	
2005-2009		-0.78
1/14/2009	90.57	
1/9/2007	88.45	
1/3/2005	93.72	
1999-2002		9.22
1/3/2002	82.92	
3/13/2001	70.55	
12/29/1999	64.33	
1988-1996		5.07
4/24/1996	64.95	
1/26/1993	43.83	
12/14/1988	27.63	

Between 1998 and 2003, the human impact affecting the Jiudian Island was the Deep Water Navigation Channel project. During this time period, the shoreline kept advancing towards the sea water and the progradation rate was $9.22 \text{ km}^2/\text{yr}$ nearly doubled the rate for 1988-1996(**Table2**). The end point rate was also calculated for the time from 1999 to 2002 and shown in (**Fig.10**). From **Fig.10**, it can be seen that most of the sand bodies enlarged and extended except that there was a small erosion pattern in the west part. The end point rates of different parts were different from each other. Here we divided the island into four parts to explain their end point rates. In the east part, the shoreline steadily moved towards the sea with an average rate about $500\text{m}/\text{yr}$ and due to the construction of the Navigation channel, the end point rate of the transects near the jetty was much higher which could reach $1000\text{m}/\text{yr}$. In the west part, the average end point rate was $200\text{m}/\text{yr}$. In the north part, since the groins and dykes stabilized the shoreline, the end point rate was the lowest among these four parts which could be only $10\text{m}/\text{yr}$. In the south part, the shoreline grew very fast. The highest end point rate among all the profiles was in this part, about $1130\text{m}/\text{yr}$.

After 2003, besides Deep Water Navigation Channel project, the decreased sediment load caused by the closure of the Three Gorges Dam would also start affecting the Jiudian Island shoreline movement. During this time period, Jiudian Island turned from deposition to erosion. The retreat rate was $0.78\text{km}^2/\text{yr}$ and the average end point rate was $-24.5\text{m}/\text{yr}$. From **Fig.11**, it can be seen that most of the sand bodies advanced much lower than the previous periods and most parts of the shoreline were retreating, especially in the south part, where the erosion was most severe with a highest rate of $-489\text{m}/\text{yr}$. The only two zones with higher

progradation rate were the places near the groins where the rate can still be as high as 200m/yr. The other parts of shoreline were in an erosion phase.

Nevertheless, after the Deep Water Navigation Channel project was completely finished in 2009 and a new groin was built near the south jetty **Fig.12**, the shoreline remained to advance into the sea with the largest progradation rate among all the time periods. From **Fig.13**, it can be seen that the largest End Point Rate occurred in the tail part (south and east parts) of the island. The double groins also can be seen from this figure. Although the annual sediment load was still low in this time period **Fig.14**, the shoreline of Jiudian Island did not continue to erode and contrarily deposited plenty of sediments in the tail part near the jetty.

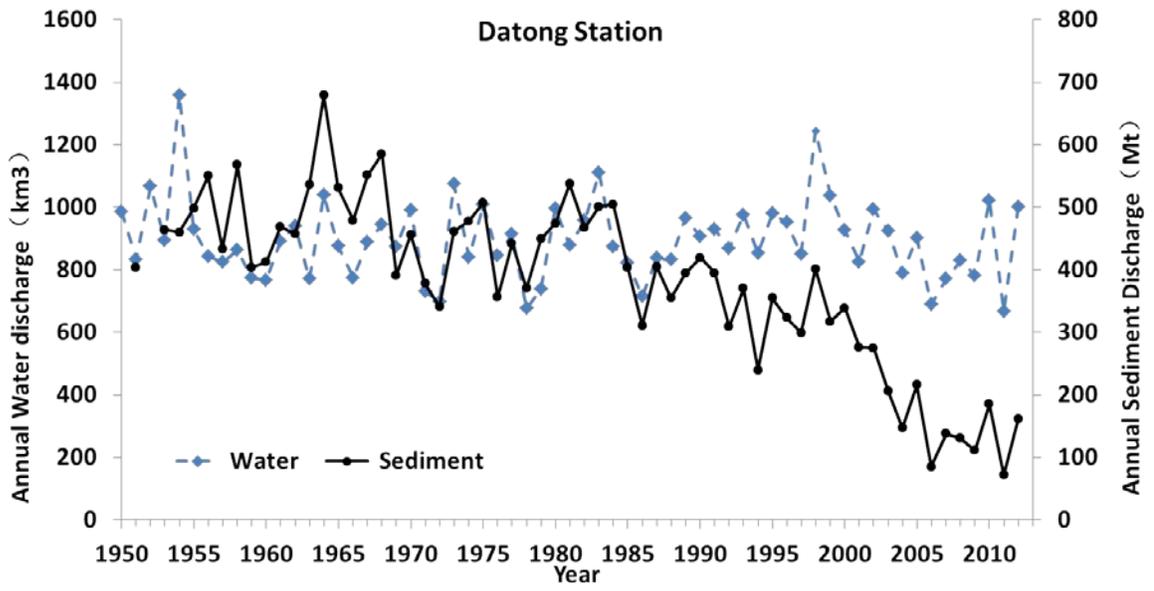


Fig.7 Annual water and sediment discharge at Datong station

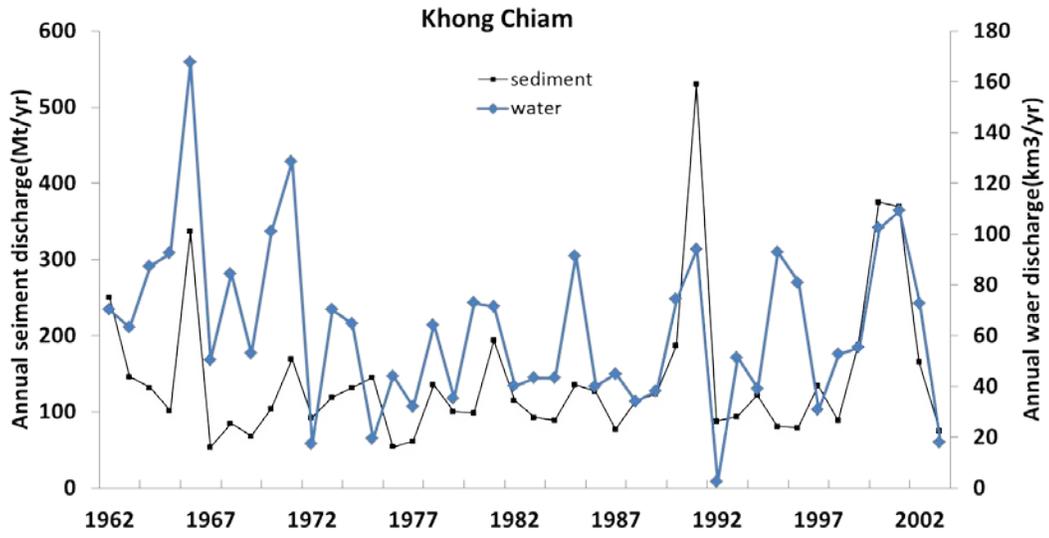


Fig.8 Water and Sediment discharge in Khong Chiam

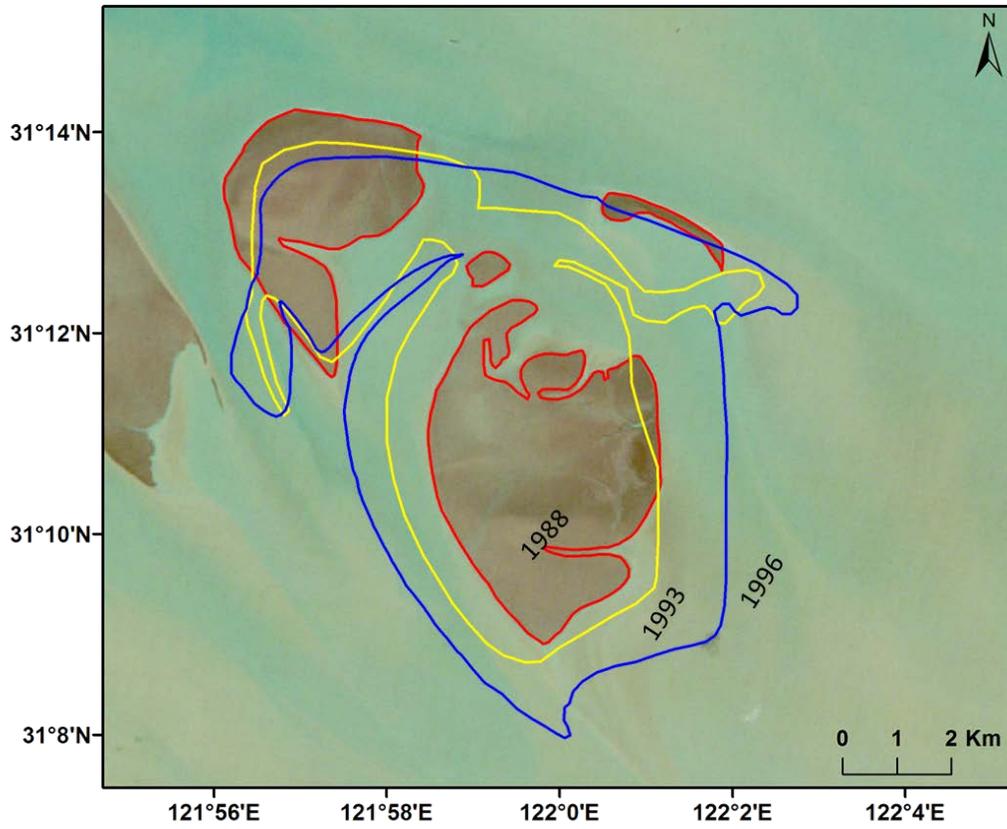


Fig.9 shoreline change from 1988 to 1996



Fig.10 shoreline change from 1999 to 2002

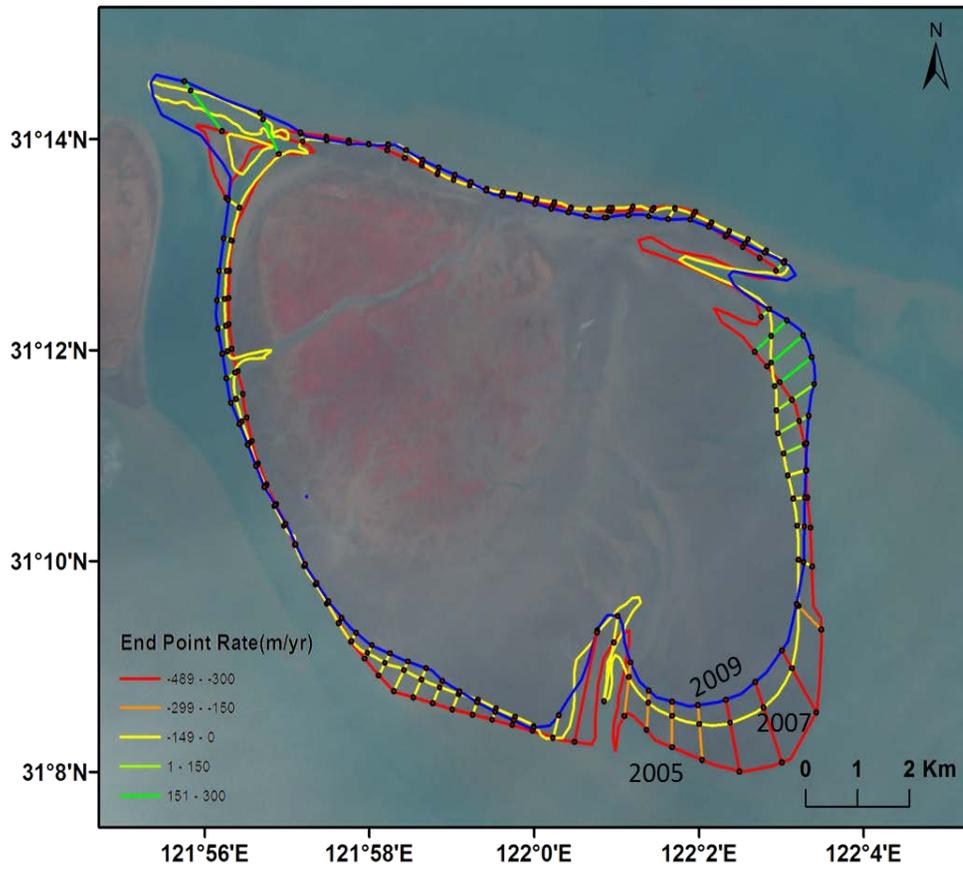


Fig.11 shoreline change from 2005 to 2009

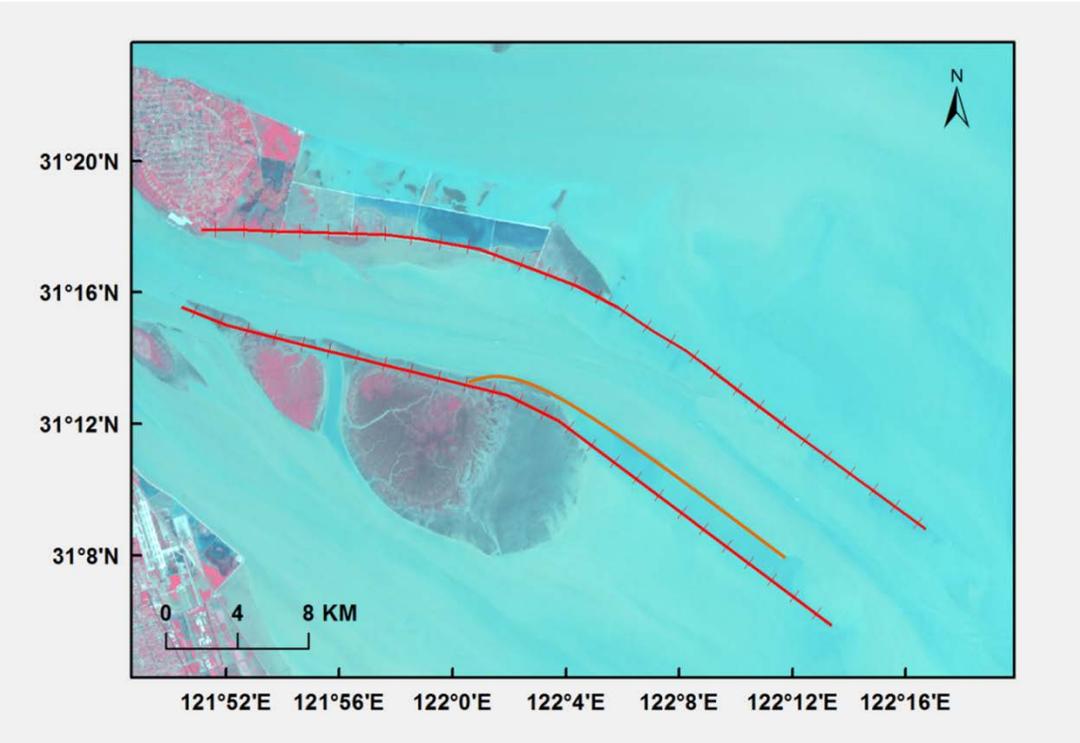


Fig.12 Jiuduan Island and a newly built jetty in 2009

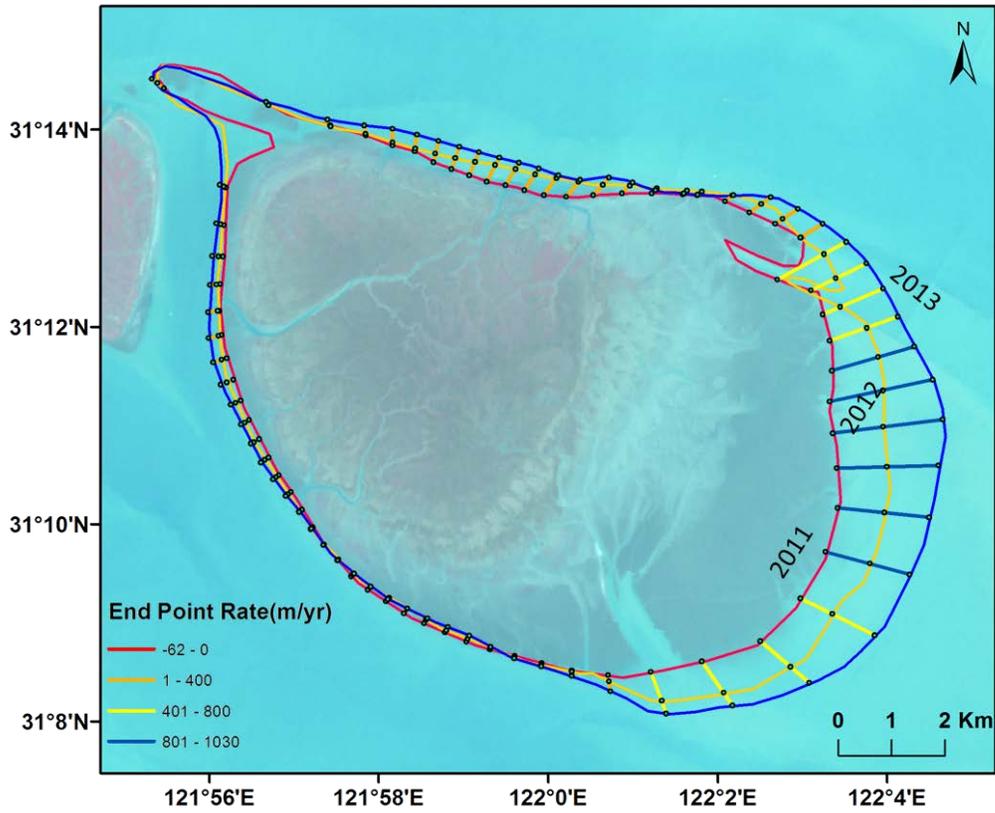


Fig.13 shoreline change from 2011 to 2013

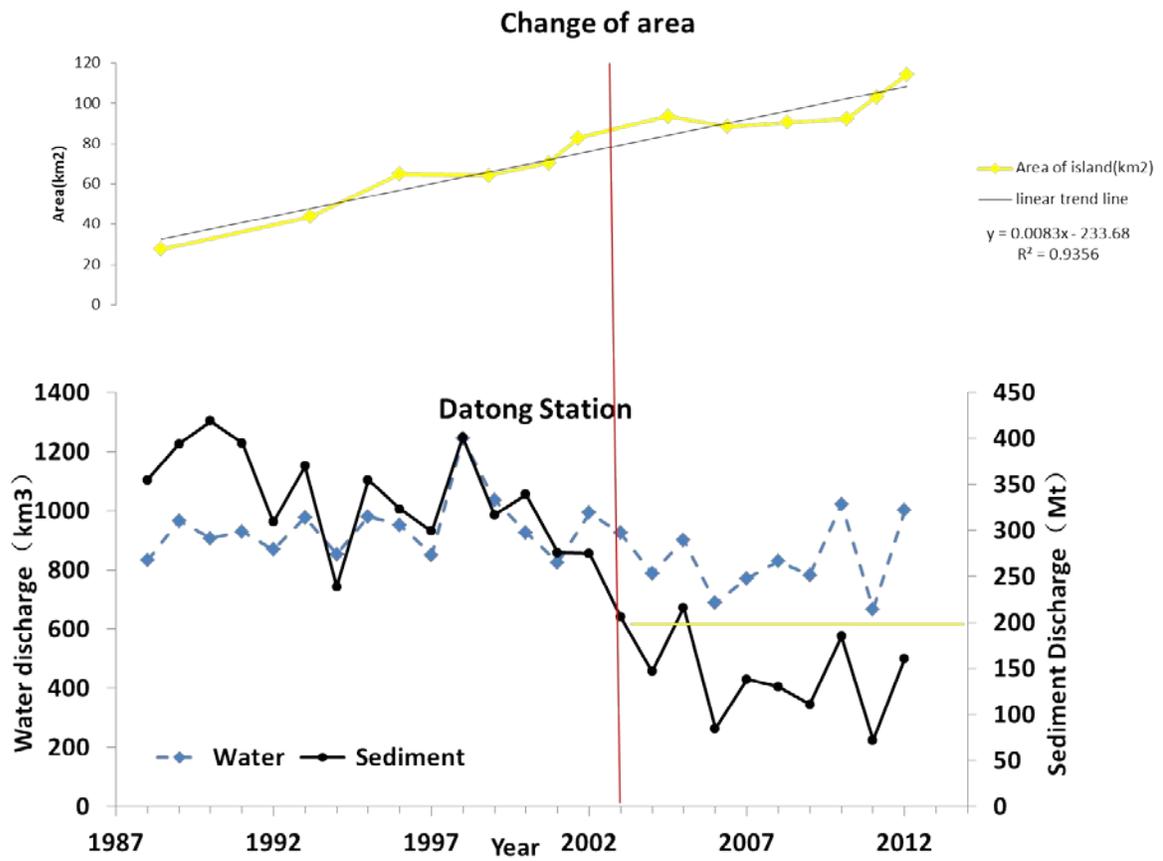


Fig.14 Area change of Jiudian Island and the water and sediment discharge from 1988 to 2013

4. Discussion

4.1 Shoreline change results and trend

Because of the human intervention such as dam construction and deep water channel project, the shoreline changes differently from different time periods. From 1988 to 1996, the upper part of the sand body moved towards southeast and finally attached to the lower part. In this process, tidal creek also developed in the island and it was narrowed down from 1993 to 1996 (**Fig.9**). From 1999 to 2002, the island kept expanding especially in the southeast part. From the results of these two time intervals, it can be seen that largest shoreline changes occurred along the northwest to southeast direction while shoreline changes in other directions were comparably slight (**Fig.10**). Yangtze estuary is a typical estuary where tide dominates, but the ebb current is stronger than the flood current in the estuary especially in flooding season due to the large water discharge from Yangtze River(Li et al., 2000b). Therefore, most of the sand bars in Yangtze estuary showed erosion in head part (northwest) and silt in tail part (southeast) and the eroded sediment was transported along the flanks of the sand body downstream.

After 2003, the closure of the Three Gorges Dam caused the decreased sediment discharge from Yangtze River. Compared to the steady advance of the shoreline before 2003, the shoreline retreated about 24.5m/yr between 2005 and 2009 (**Fig.11**). This is consistent with the results in eastern Chongming Island, where changes in topographic profiles showed that the progradation rate was about 2km/yr before 1990, but after 2003

the progradation rate reduced to about 100m/yr and the mudflats were eroded vertically (Yang et al., 2011).

However, the shoreline of Jiuduan Island did not continue retreating. From 2011 to 2013, the tail (Southeast) part of Jiuduan Island switched to deposition with a maximum rate of about 1000m/yr (**Fig.13**). Although the annual sediment discharges were still below 200Mt/yr, the shoreline changes situation seemed to be back to the pre-dam period. There were several reasons may cause the continuation of the shoreline advancing into the sea.

First, despite the fact that sediment load from Yangtze River was dramatically decreased; the sediment carrying capacity was still very large in Yangtze Estuary. The tidal current is strong. During spring tide, the maximum velocity can be 3.5m/s and average velocity can be 1.2m/s (Li et al., 2000b). The wave energy is also very high especially in the tail part of the island. The tail side of the island is a high wave energy area with mean and maximum wave heights of 1.0m and 6.2m respectively, while the head side of the island is a low wave energy area with 0.2m in mean wave height and 3.2m in maximum wave height. The suspended sediment concentration is very high in the intertidal area which is generally 1-3 g/l (Yang et al., 2000). All these conditions provide a very large sediment transport capacity in the Jiuduan Island area.

Second, the jetty built along the Jiuduan Island changed the redistribution circumstance around the Jiuduan Island. Because of the sediment trapped behind dams constructed along Yangtze River, Yangtze River has already experienced sediment

starvation. In the Yangtze subaqueous delta, erosion already had occurred in the delta front primarily in depth between 5m and 8m below low tide (Yang et al., 2011). However, the sinks for these eroded sediment is not clear. These sediments may export to offshore or they can also be transported by the strong tide current to the shallower area. From **(Fig.11)**, although most of the island experienced erosion, the shoreline near the jetties can still grew at an End point Rate 300m/yr. So if the eroded sediment from the deeper area can be transported around the shallower area, the places near the jetties will be the most possible area where sediment deposits because the jetties' trapping capacity. Another evidence was that, a new groin about 21km long was built near the south jetty which definitely influenced the shoreline change in the period between 2011 and 2013. During that time period, the maximum End Point Rate was 1000m/yr and the fast growing places were all near the newly built groins and jetties.

Third, the division ratio of ebb flux was reduced in the north passage due to the resistance effect of the deep navigation channel construction. From 1997 to 2005, this ratio decreased from 0.64 to 0.45 and this decreasing trend would continue (Hu and Ding, 2009). Therefore, more of the water and sediment from upstream will be discharged into south passage where Jiudian Island locates **(Fig.15, Fig.16)**.

Finally, although the overall sediment flux from Yangtze River is largely decreased, in Jiudian Island regional factors such as the wave, tides and the engineering constructions seem to be much more significant in affecting the shoreline changes. However, it is still uncertain that when shoreline change in Jiudian Island can reach its

equilibrium state as a result of these complex factors and at the equilibrium state what the threshold value is for the Yangtze River sediment flux to trigger Jiudian Island's conversion from deposition to erosion.

4.2 Comparison with Mekong River Delta

Mekong River is another major river in Asia and the impact of upstream damming on water and sediment flux also has raised great concern among scientists (Syvitski et al., 2009; Wang et al., 2011a; Wang et al., 2011b). Similar to Three Gorges Dam in Yangtze River basin, the completion of Manwan dam in 1993 in Mekong River basin also caused arguments. However, the circumstances of the sediment flux were different between these two major rivers. The sediment flux from Mekong River didn't decrease as much as Yangtze River. In fact, according to Wang et al. (2011b) the sediment flux was increased in the period from 1993 to 2003 (**Fig.8**). In Mekong delta area, there were no major coastal engineering projects (**Fig.5**). So these islands in Mekong River behaved more naturally than Yangtze River. This was consistent with the shoreline change results. The sediment flux in 1995 and 1996 was very low. The shoreline changes for both island A and B also retreated from 1989 to 1996 (**Fig.17, Fig.18**). In 2000 and 2001, there were two peak values of the sediment discharge and in 2002 the sediment discharge decreased down to 165.3Mt/yr which was close to the value 123.5Mt/yr in 1989 and the shorelines of the two island advanced near the shoreline in 1989 (**Fig.19, Fig.20**). Compared with Yangtze River, there were more flooding events and storm surge inundations in Mekong

River and the sediment supply from the channel or tributaries was larger. These factors may reduce the significance of the dam and reservoir trapping effect.

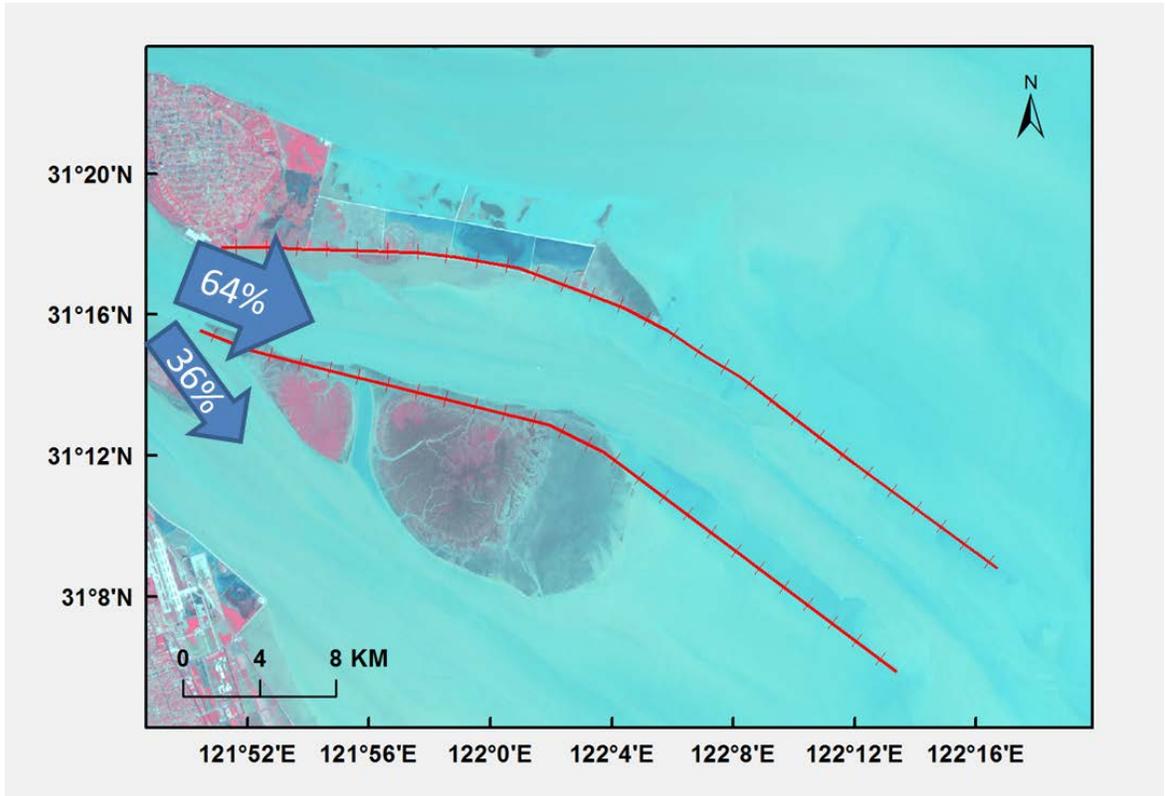


Fig.15 ebb flux ratio in 1997

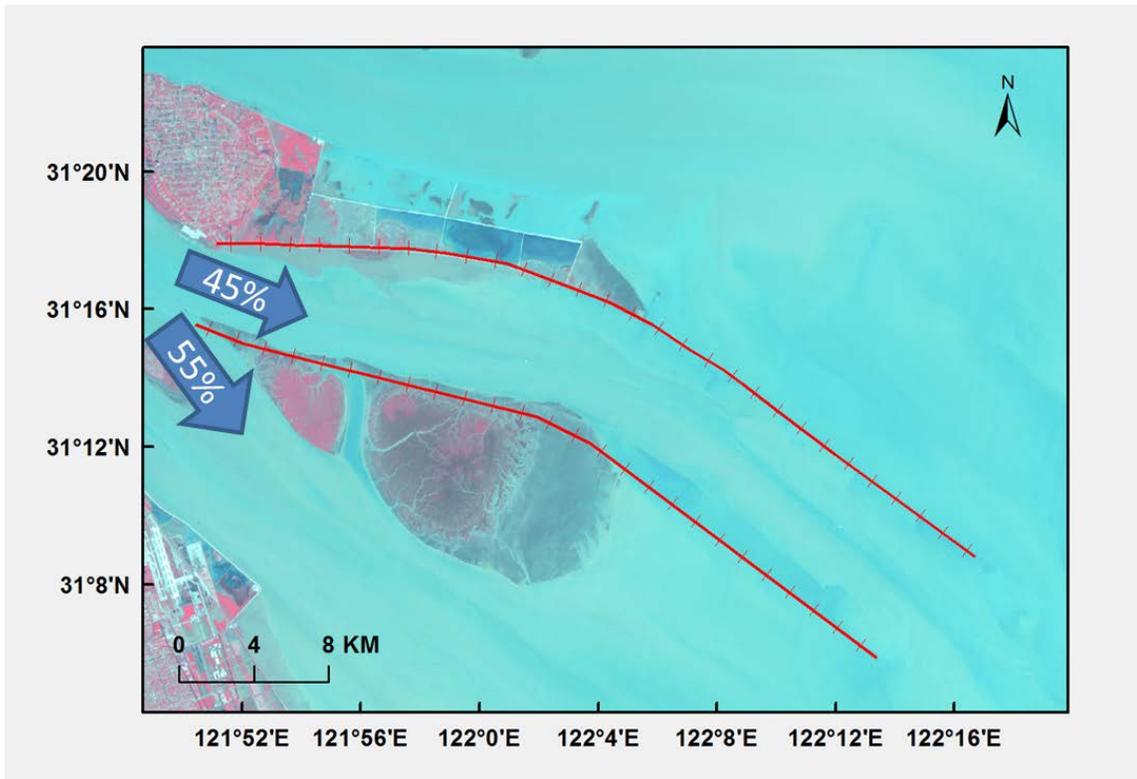


Fig.16 ebb flux ratio in 2005

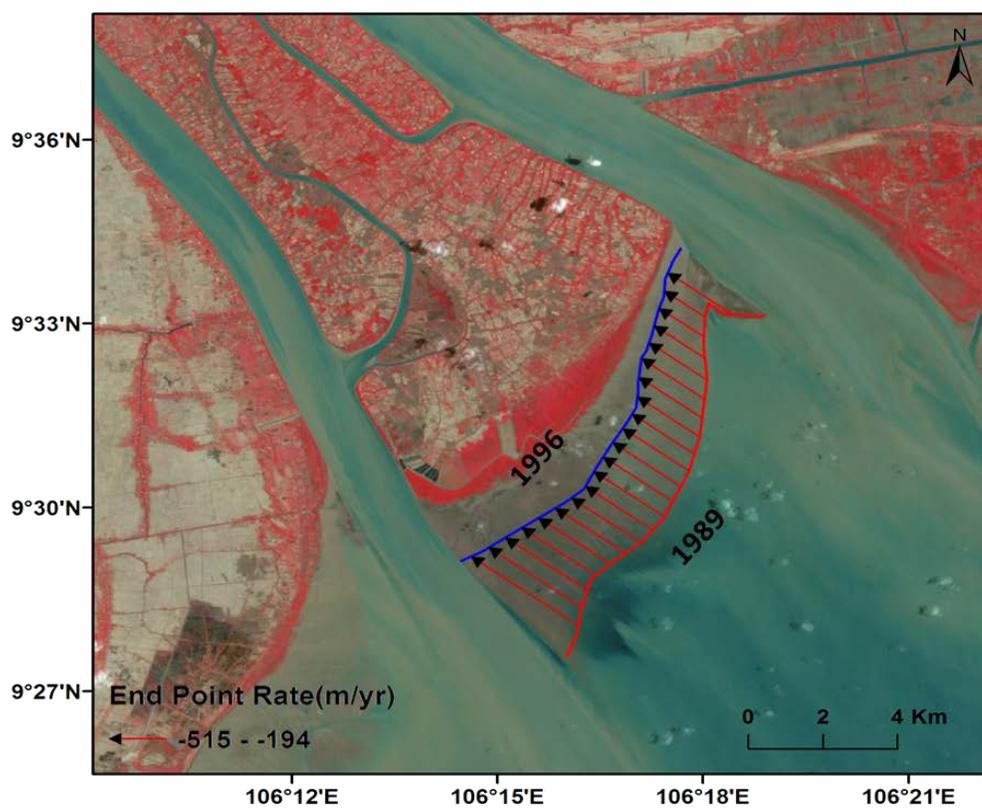


Fig.17 shoreline change of island A from 1989 to 1996

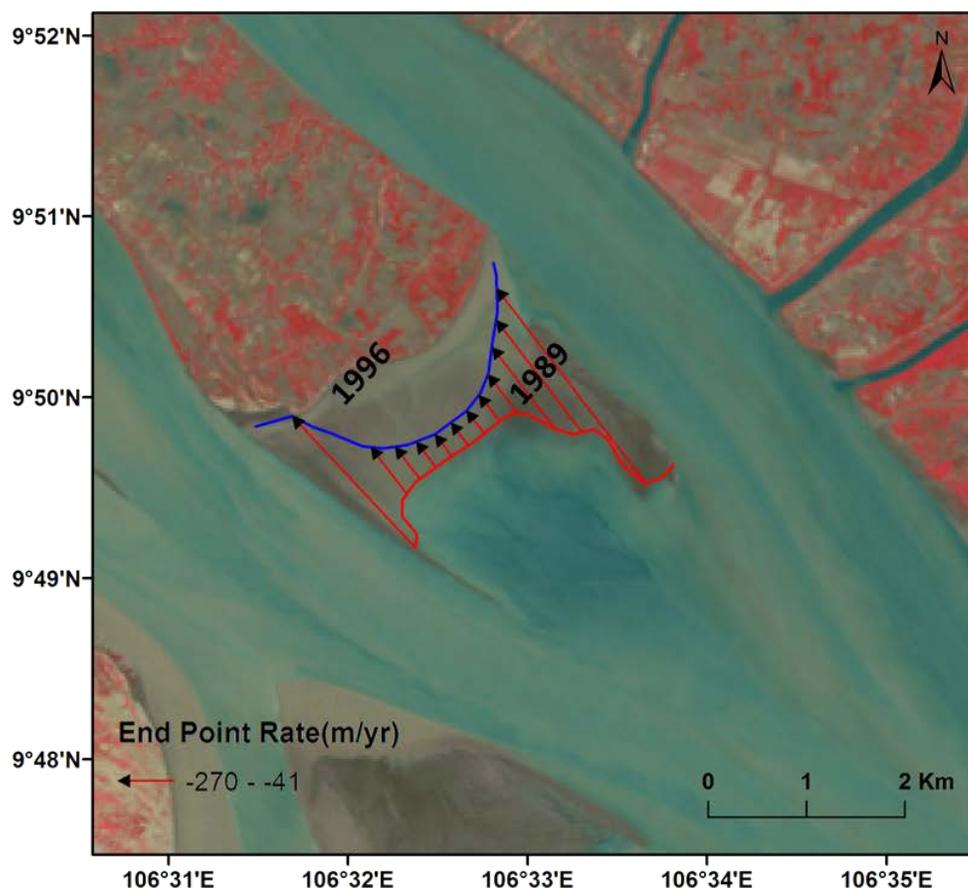


Fig.18 shoreline change of island B from 1989 to 1996

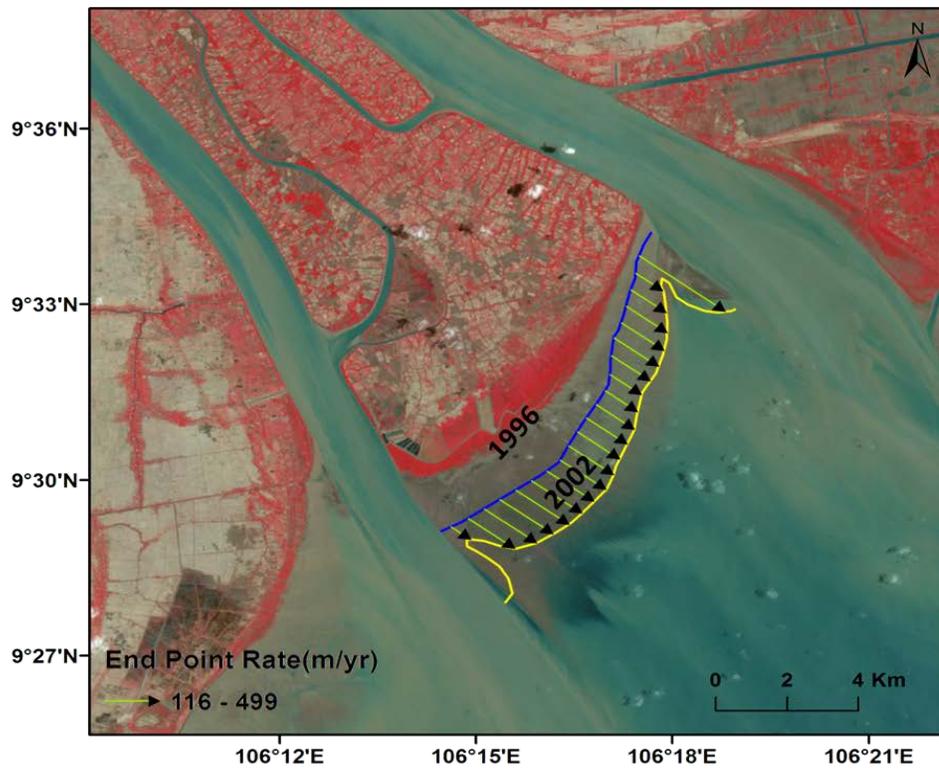


Fig.19 shoreline change of island A from 1996 to 2002

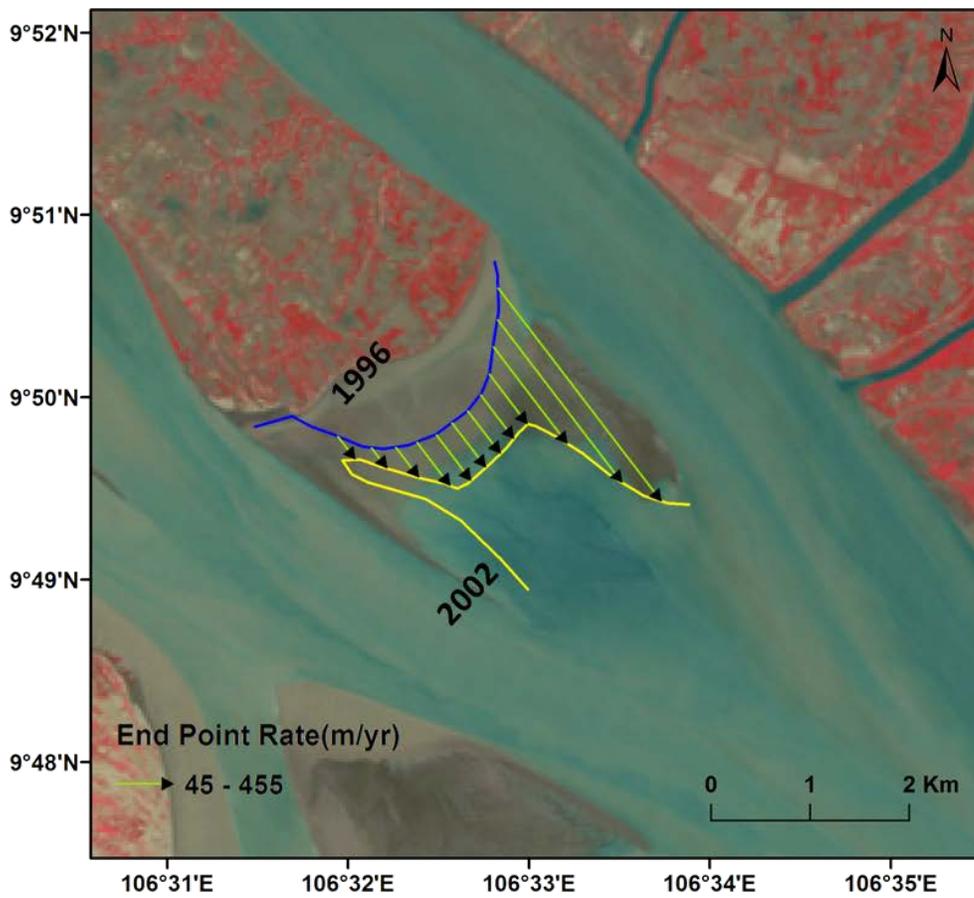


Fig.20 shoreline change of island B from 1996 to 2002

5. Conclusion

With the closure of Three Gorges Dam in 2003 and the completion of Deep Water Navigation Channel project in 2009, nowadays the water and sediment flux from Yangtze River and the Yangtze Delta are highly human manipulated.

The results of the shoreline changes in Jiuduan Island from a time series of Landsat images illustrate that both the dam construction and the coastal engineering project have their impacts on the development of Jiuduan Island shoreline. However, these two major human impacts function differently. Dams and reservoirs trapped a lot of sediment behind causing the decrease of the sediment flux into the ocean and in Yangtze River Delta the starvation of sediment would cause the erosion of Jiuduan Island. Jetties built along Jiuduan Island not only stabilized the shoreline around the construction, but also changed the former sediment transport process bringing more sediment deposited around the jetties. That is the reason why the shoreline of Jiuduan Island still continued growing without sufficient sediment supply from Yangtze River from 2011 to 2013. In regional scale such as the mouth bar area, engineering constructions has more significant impact, but in a long term, the reduced sediment flux will cause the erosion of Yangtze River Delta.

The sediment flux from Mekong River didn't decrease as much as Yangtze River. This may be a result of more flooding events and storm surge inundations in Mekong River and the larger sediment supply from the channel or tributaries. These factors may reduce the significance of the dam and reservoir trapping effect. Since there was no major coastal

engineering projects in the islands in Mekong. The positive correlation between the shoreline change of the mouth bars and the sediment flux was more obvious.

However, problems such as when Jiuduan Island can reach its equilibrium state are still unclear. Sediment transportation inside the Deep Water Channel by dredging and outside the channel by tides and waves in Yangtze River need to be combined to fully understand the morphology changes in the river delta. Future work also need to be focused on keeping monitoring the water and sediment flux from Yangtze and Mekong River and exploring a correct relationship between these fluxes and the delta evolution in world major river deltas.

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