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Coastline change detection with satellite remote sensing for environmental management of the Pearl River Estuary, China

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ABSTRACT

The Pearl River delta area in Guangdong Province has one of the highest economic development rates of China. Rapid industrialization and urbanization has resulted in extensive changes in land use, including the construction of harbours and embankments. The lack of sustainable coastal zone management has caused severe environmental problems, such as land subsidence, intrusion of sea water, siltation of river channels and coastal erosion. For the analysis of the changes of the coastlines, multi-temporal Landsat images and a SPOT scene have been used, in combination with topographical and nautical data. From the change analysis, it can be concluded that the largest variations in the position of the coastline over time occurred in the Nansha Development Zone, situated in the Northern part of Lingdingyang bay. Sedimentation and land reclamation was responsible for the growth of the islands in the period 1960 to 2000, which however decreased slightly in the years after. Various large changes occurred also in the East of the bay along the coast of Shekou peninsula, caused by extensive harbour construction and growth of polder systems. Based on the research of the coastline change in recent decades, suspended sediment plume distribution and its sedimentation, it is suggested that the western part of the waterway in the estuary may not be suitable for large number of construction for harbours, due to the sedimentation and fill up. One of the most important impacts of the coastline changes in the Pearl River Estuary is the narrowing down and extension of river channel which results in more floods in the upper part of the river.

1. Introduction

This study explores the use of multi-temporal satellite images for coastline change analysis of the Pearl River deltaic area in Guangdong Province, China. Coastline mapping and coastline change detection are critical for safe navigation, sustainable coastal resource management and environmental protection. The catchment of the Pearl River is with 453,700 km^2 the largest in southern China, and includes the West, North and East rivers. The Pearl River enters the South China Sea via eight outlets, of which the Humen outlet is the largest (Fig. 1).

The Pearl River deltaic area is one of the fastest developing regions in China. In the last two decades the Province's GDP grew at an average annual rate of over 10% (Guangdong Statistical Bureau, 1998). Total import and export value of Guangdong Province account for about 1/3 of mainland China. The Linding water way in Humen is the main sea-route for shipping.

The rapid industrialization and urbanization in the Pearl River area has resulted not only in extensive changes in land use, but also in the loss of significant amounts of agricultural land (Weng, 2002). At the same time, lack of appropriate land use planning and measures of sustainable development have led to several environmental problems, such as land subsidence, intrusion of sea water, siltation of river channels and erosion and sedimentation along the coast.

Knowledge of the coastline is the basis for measuring and characterizing land and water resources (Liu and Jezek, 2004). Coastline mapping and change detection are essential for safe navigation, resource management, environmental protection, and sustainable coastal development and planning (Di et al., 2004). The enormous development speed of the Pearl River area makes it difficult to detect most of the coastline changes in time by traditional measurements (Zhu, 2001). However, remote sensing can be an effective tool to map the changes in a fast and cost effective way (Chen and Rau, 1998; El-Asmar, 2002; Shaghude et al., 2003; Chong, 2004; Hennecke, 2004).

Examples of studies to detect coastline changes in China with remote sensing are from the Yellow River delta (Yang, et al., 1999; Li et al., 2004; Chang et al., 2004), the Bohai sea (Jiang, et al., 2003; Huang and Fan, 2004) and the Fujian coast (Sun and Zhang, 2004). Also from the Pearl River delta successful studies have been carried out on coastline change and urban expansion using multi-temporal satellite images (Li and Yeh, 1998; Zhu, 2001; Xue and Chai, 2001; Huang et al., 2004). These studies show that most of the coastline change is caused by land reclamation and the construction of

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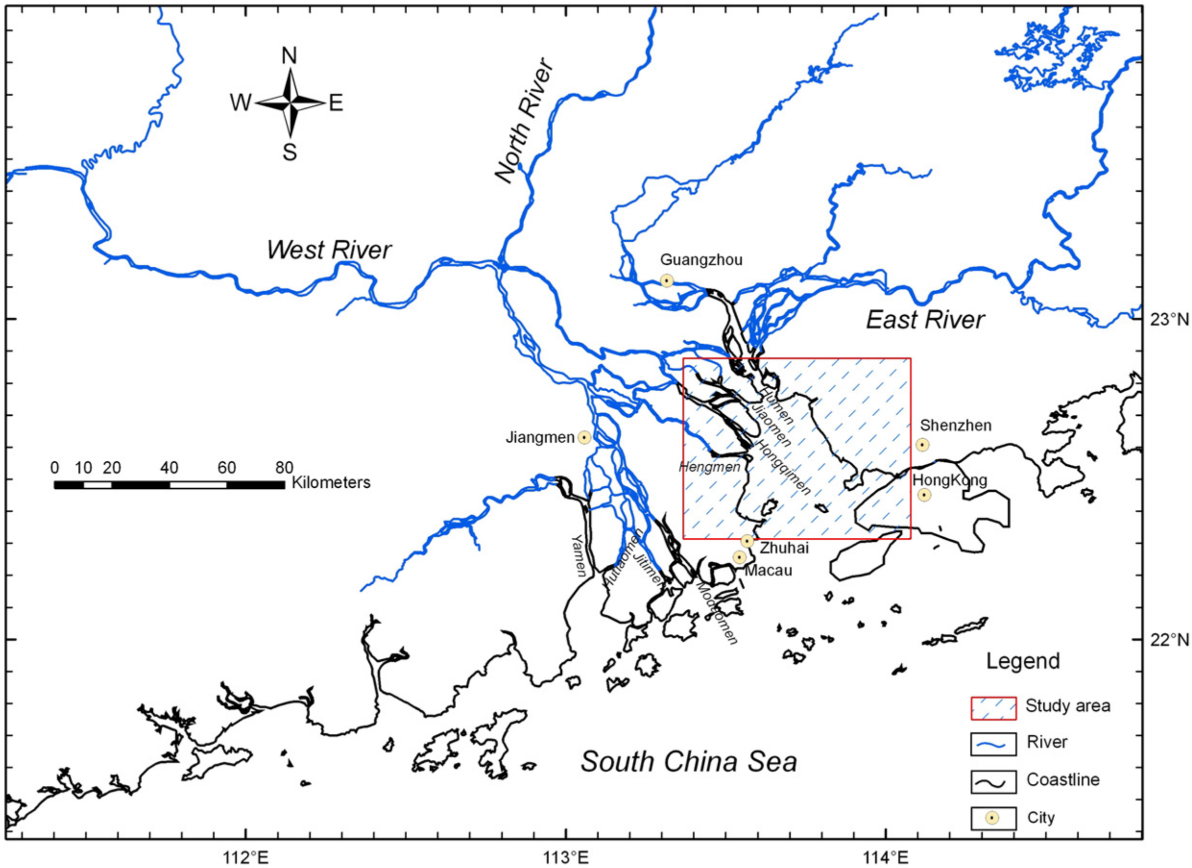

Fig. 1. Location map of the study area.

embankments along the rivers, and that the effects of tides and waves on this are relatively small.

2. Research methodology and data used

The research methodology includes the following steps: a) data collection, b) image data processing and 3) visual and digital analysis of the coastline changes in time (Fig. 2).

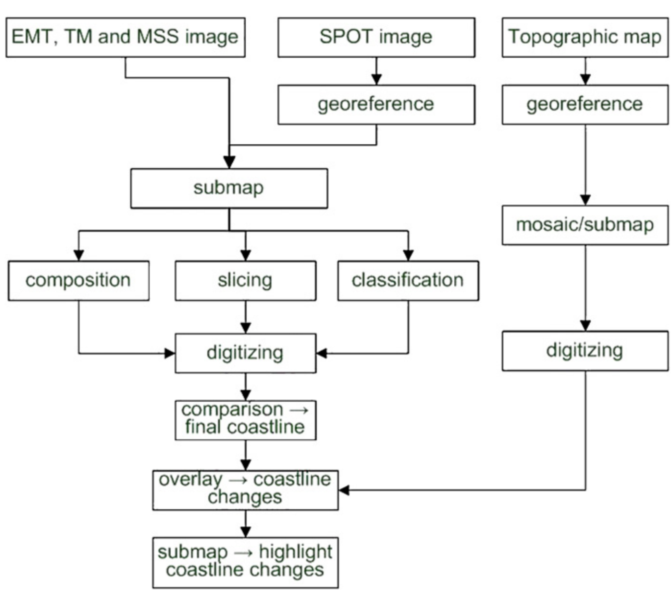

Fig. 2. Flowchart of research procedure.

2.1. Data collection

For the multi-temporal analysis use could be made of a Landsat MSS image of 1979, as Landsat TM and ETM+ images of resp. 1990 and 2000, which were downloaded for free from the internet site http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp.

Also available was a SPOT image of 2003 and the topographic map 1:100,000 of 1966 and a nautical map scale 1:150,000 of 2003. Tidal data from the time of acquisition of the images was also collected from South China Branch of State Oceanic Administration (Table 1).

2.2. Image data pre-processing

Image pre-processing is the process of making images more interpretable for a particular application. Geometric correction, false colour composition, image mosaic and submap were used in the paper. The Landsat images were already georeferenced, but the SPOT

Table 1
Acquisition time, resolution and the local tidal level of the images used in the research.

Name	Acquisition day/publication time	Local time	Spatial resolution/ scale	Tidal level (Neilingding I.)	Tidal difference
Landsat ETM+	2000-9-14	10:40	30/15 m	−267 cm	0
Landsat TM	1990-10-15	10:20	30/15 m	−212 cm	55 cm
Landsat MSS	1979-10-19	10:10	80 m	−229 cm	38 cm
SPOT XS and Pan	2003-11-7	9:16	20/10 m	−226 cm	41 cm
Topographic map 1:00,000	1966		1:100,000		
Nautical map 1: 150,000	2003		1:150,000		

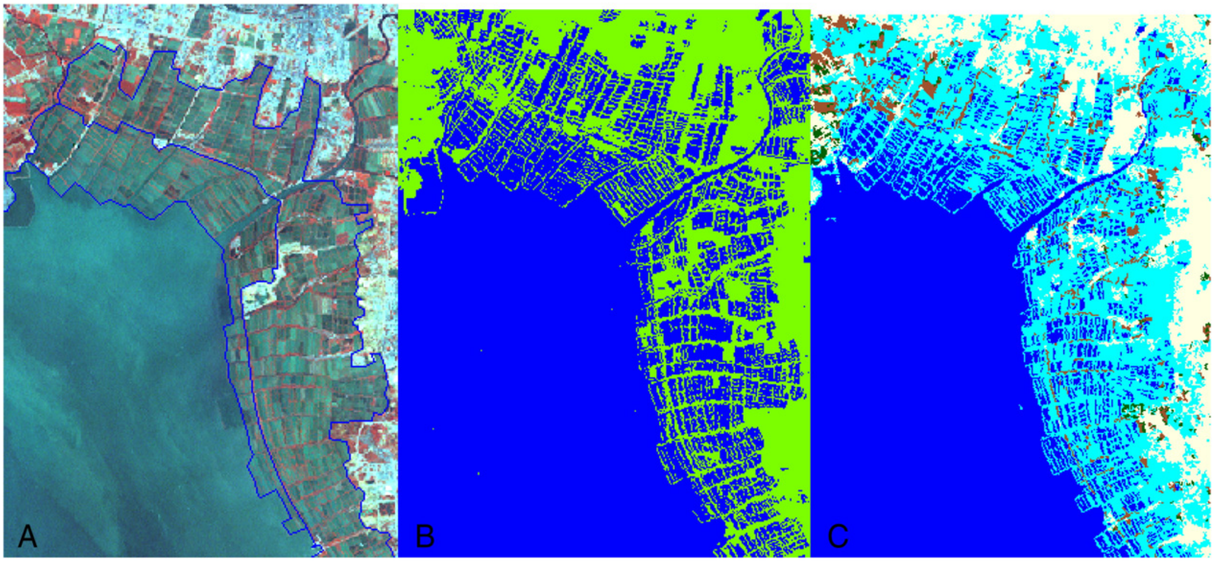

Fig. 3. Comparison among composition map of the Lansat ETM Image (A), binary slicing map (B) and classification map (C).

image and scanned topographic maps were not. Therefore they were georeferenced to the Landsat ETM image, in order to keep the same coordinate system.

Different band false colour combinations were tested for coastline and river bank extraction. It is found that bands 7, 4, 2 for RGB was found to be most effective for mapping coastline and river band, while the bands 3, 2, 1 for RGB to be most effective for suspended material and composition of bands 4, 3, 2 for RGB to be most effective for vegetation.

2.3. Visual and digital analysis

The coastline can be defined as the boundary between water and land. As the reflectance of water in near infrared is much lower than of land

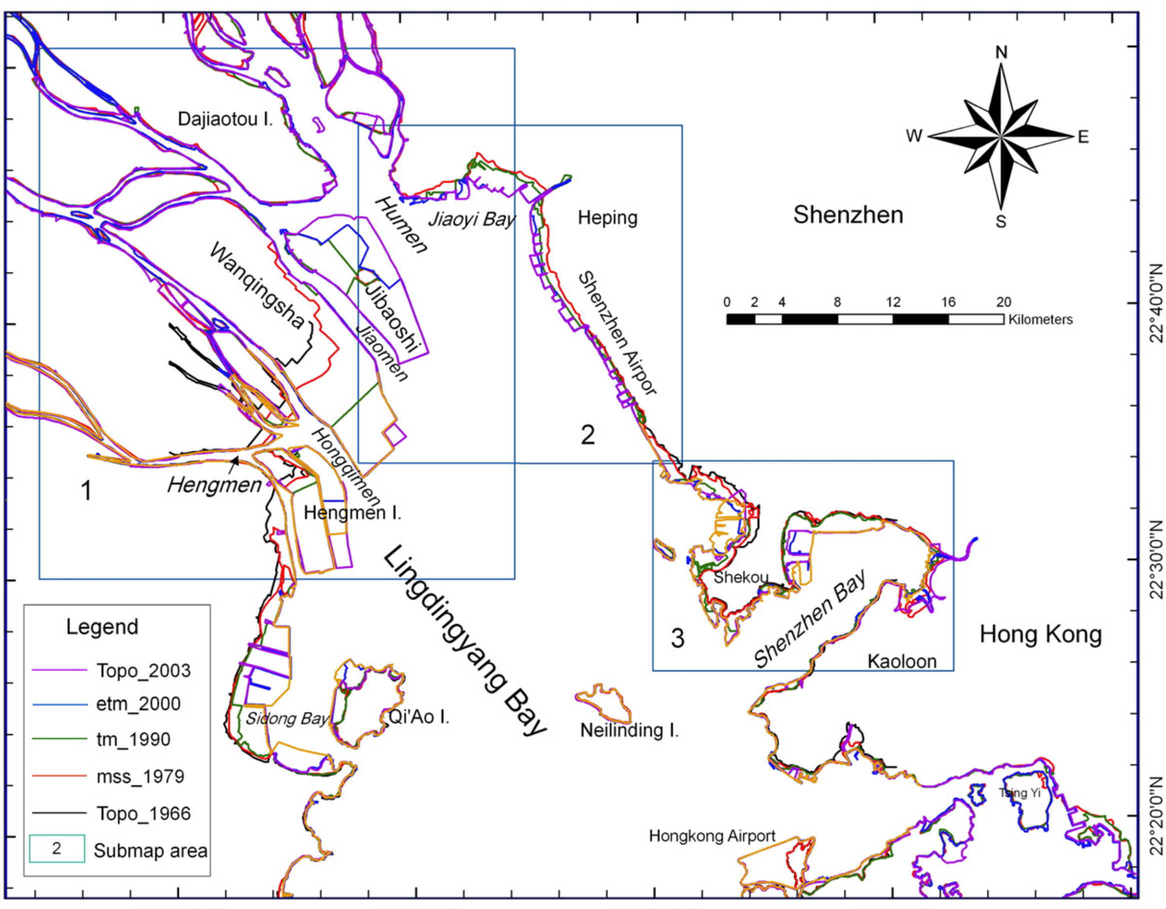

Fig. 4. Coastline changes of the Pearl River estuary since 1960 s and sub-maps of study areas.

cover, band 5 of Landsat ETM and TM image, band 4 of Landsat MSS image and SPOT image are selected for the binary slicing to define the coastline. It is found that the slicing map usually is better than composition image for digitalising coastline, especially in some wetlands (Fig. 3).

Both methods are not suitable for images with clouds. The supervised classification of land in ERDAS can better solve the problem, especially for the Landsat TM image which was covered by clouds in the south-eastern area. Five classes of built-up area, water, forest, plantation and bare land have been classified for the Landsat ETM image. But built-up and bare land was combined into one class in the Landsat MSS, TM and SPOT image.

3. Coastline changes in recent decades

After the coastlines were extracted from Landsat MSS image of 1979, Landsat TM image of 1990, Landsat ETM image of 2000, SPOT image of 2003, as well as from topographic map of 1966 and nautical map in 2004, they were overlaid in ArcGIS for detecting their changes in the period (Fig. 4). In order to highlight the local changes, 3 sub-maps were created (Figs. 5 to 7).

3.1. Nansha Development Zone

The Nansha area is located in the North-Western part of Lingdingyang bay and includes four outlets of the Pearl River. With a very high economic growth rate during recent years, it can be considered as the most important development zone of the Guangzhou authority. The coastline changes are the largest of the study area (Fig. 5). This is mainly caused by reclamation of accreted land, especially in the islands of Jibaosha, Wangqingsha and Hegmen.

The small Jibaosha Island for instance expanded rapidly after 1979, from a surface area of only 1.1 km^2 up to 11.8 km^2 in 1990. The average rate of expansion in this period is therefore almost 1.0 km^2/yr. This trend increased until an area of 36.2 km^2 in 2000 up to even 47.4 km^2 in 2003, with growth rates of 2.4 km^2/yr and 3.7 km^2/yr respectively (Table 2).

Other islands show similar trends, although the growth rate of Wanqinsha Island after 1970 was less compared to Jibaosha due to more and more suspended material was blocked by the Jibao Island, as it expanded.

Hengmen Island was originally composed of 3 small islands, which joined together in 1979, due to sedimentation processes and reclamation activities. It expanded to 7.4 km^2, 27.7 km^2 and 33.5 km^2 in 1990, 2000 and 2003 respectively.

The growth of Jibaosha Island took place in all directions. This was however not the case for the Wanqingsha and Hengmen islands, which expanded mainly towards the Southeast. The lines A and line B indicate the linear extension of the two islands (Fig. 5).

Wanqingsha Island (line A) extended from 1966 until 1979 almost 1900 m in total with an average rate of 146 m/yr. This trend increased until a rate of over 431 m/yr in the period 1990 to 2000 (Table 3).

The expansion rate of Hengmen Island (line B) increased dramatically after 1990 up to almost 600 m/yr until 2000. It can be concluded that the expanded rate increased in 1980 s and 1990 s, but it decrease slightly after 2000.

3.2. Northeast region

The coastline changes in the Northeast region are less than those in the Nansha area. The largest changes occurred in Jiaoyi

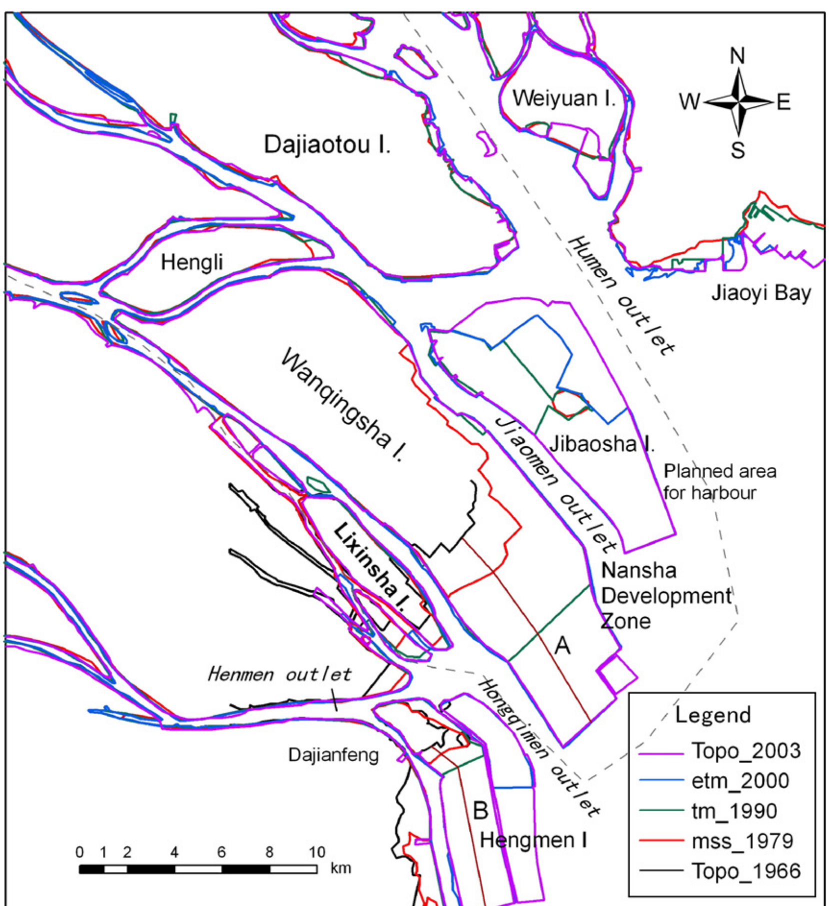

Fig. 5. Coastline changes of Nansha area.

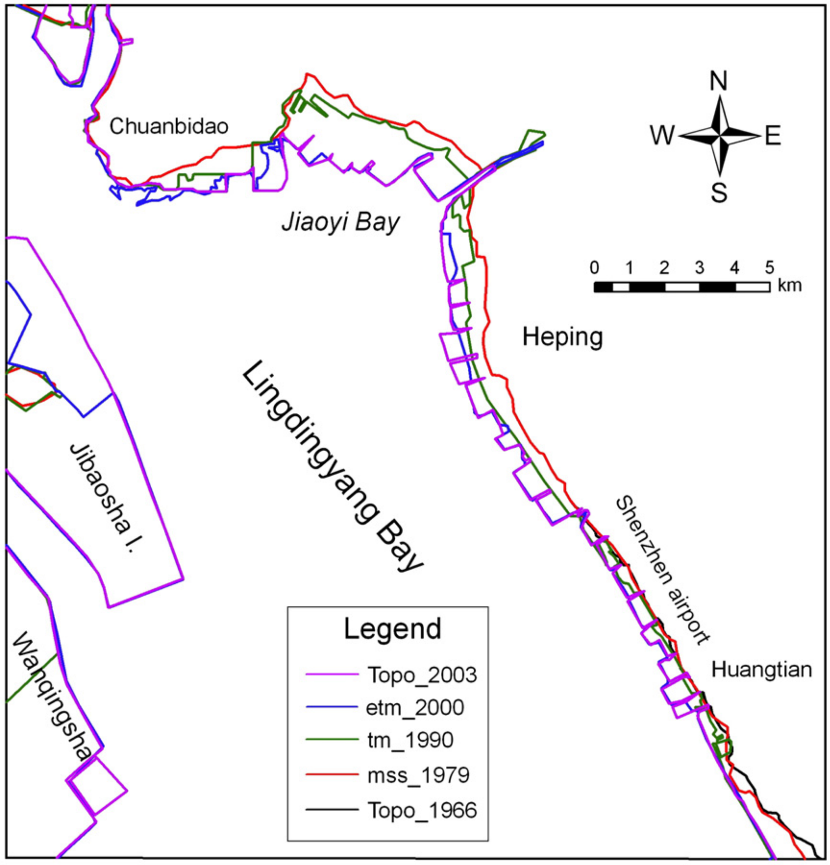

Fig. 6. Coastline changes of Jiaoyi Bay.

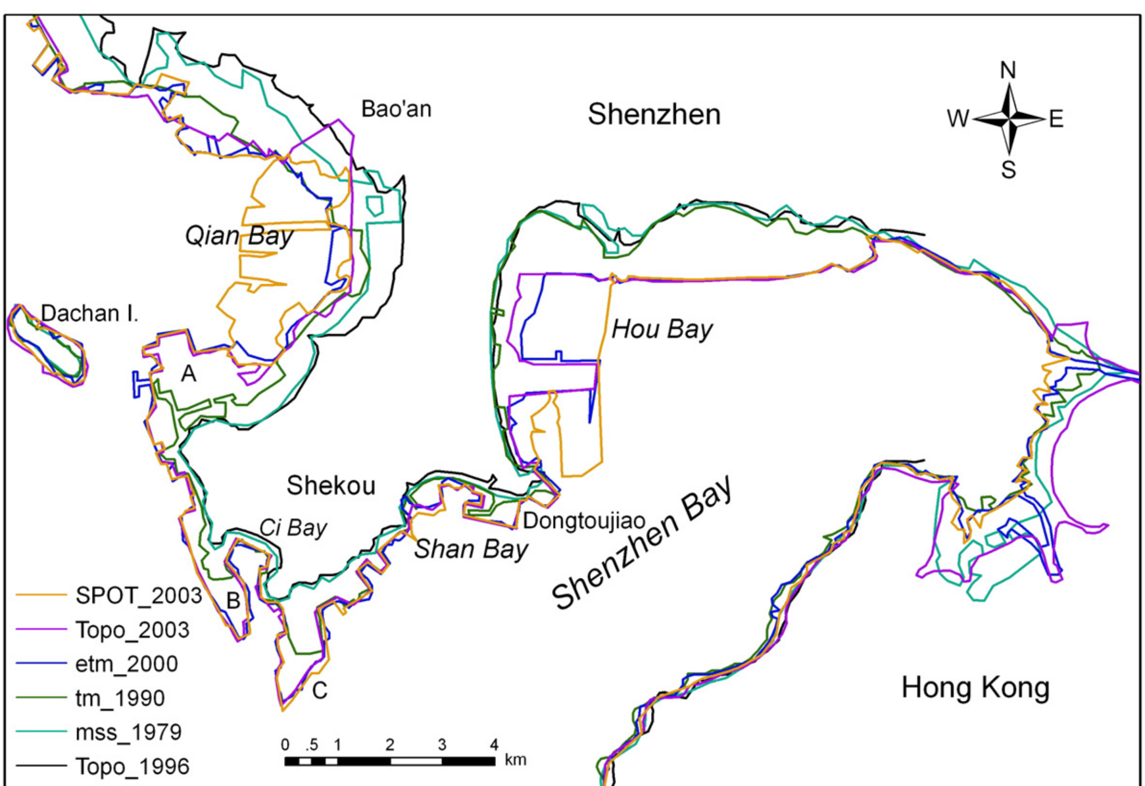

Fig. 7. Coastline changes of Shekou peninsular and surrounding coasts.

Table 2
Changes in surface areas of some islands in the estuary.

Time	Image/map	Jibaosha I./km^2		Wanqingsha I./km^2		Hengmen I./km^2		Total/km^2	
		Area	Change rate[a]	Area	Change rate	Area	Change rate	Area	Change rate
1979	Landsat MSS	1.1		92.5		4.6		98.2	
1990	Landsat TM	11.8	1.0	123.4	2.8	7.4	0.3	142.6	4.0
2000	Landsat ETM	36.2	2.4	141.0	1.8	27.7	2.0	204.9	6.2
2003[b]	Nautical map	47.4	3.7	142.3	0.4	33.5	0.4	223.2	6.0

[a] Average per year change rate from last image acquisition time.
[b] Pressed at 2004, but measured at 2003 or before.

Table 3
Coastline extension of Line A in Wanqingsha Island and B Hengmen Island.

Period	Line A in Wanqingsha I.		Line B in Hengmen I.	
	Total m	Change rate m/yr	Total m	Change rate m/yr
1966–1979	1900	146	520	40
1979–1990	3280	298	790	72
1990–2000	4310	431	5990	599
2000–2003	No obvious change			

Bay, with an average coastal growth between 1979 and 2000 of 300–400 m/yr. In the next decade, the average extension increased to 1000–1500 m.

The coastline changes along the straight Heping coast in the South are much less (Fig. 6). Along this coast embankments have been constructed to protect the aquacultural pond systems.

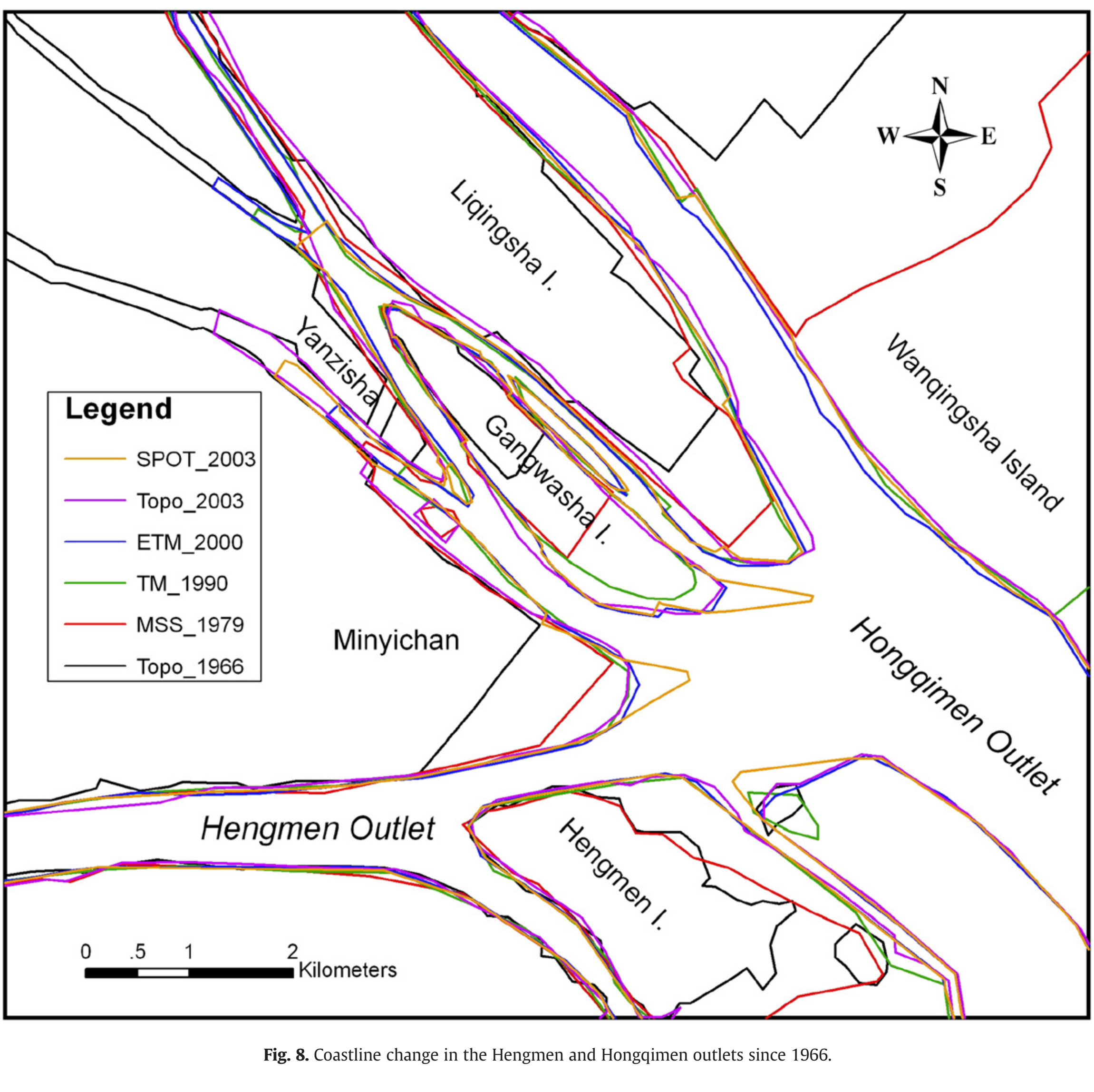

Fig. 8. Coastline change in the Hengmen and Hongqimen outlets since 1966.

Fig. 9. Comparison of the Hongqimen outlet and Hengmen outlet in 3 times: A: Landsat MSS, 1979; B: Land TM, 1990; Landsat ETM, 2000.

3.3. Shekou Peninsula and surrounding coasts

After the establishment of the Shenzhen Special Economic Zone in 1980, the Shekou peninsular developed rapidly into an important manufacturing and trading region. In particular the construction of several harbours caused a dramatic seaward expansion of the coastline, which amounted until 1990 at some places 1.1 km. Until 2000 this growth was even higher at the harbours situated at A, B and C (Fig. 7) with expansions of 1.4 km, 1.2 km and 1.0 km respectively. As by 1980 the harbour construction activities were finished, only small coastline changes took place afterward.

Qian Bay in the Northeast of Shekou peninsula is a shallow water zone. The construction of large aquacultural areas protected by embankments in the period 1966–1979 resulted in a total coastline advance of 680 m in the central part. The construction of fishponds in the South, starting only after 1990 resulted in a coastline advance of 2000 m in the top of the bay.

There were hardly any coastline changes in Hou Bay until 1979. Even in the period 1979–1990 only a few small harbours and aquacultural lands were build. This changed however in the years 1990–2000 which large constructions, resulting in a coastline advance of 2 km at some places. (Fig. 7).

As a whole, the largest change of shoreline occurs in the west bank of the bay due to sedimentation and reclamation. Substantial artificial change occurs in the Shekou Peninsular like the construction of harbours.

4. Coastline change and environmental management

An important consequence of the expansion of the land due to increased sedimentation and reclamation is narrowing of river channels. This is particularly the case in the Hongqimen and Hengmen outlets and the canals in between the islands of Gangwasha, Lixinsha, Minyichan and Yanzisha (Fig. 8). A clear example of the changes in the

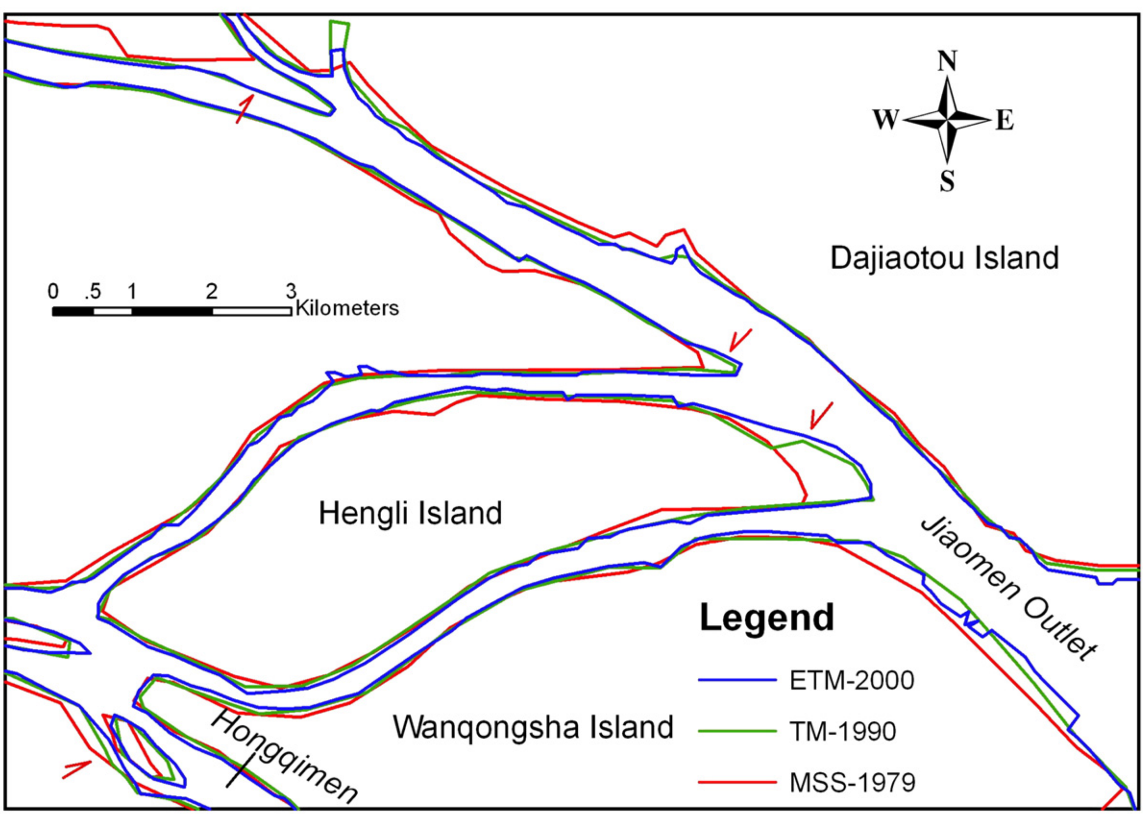

Fig.10. Narrowing of the river channels from 1979 to 2000, arrows indicate the main changes.

Hongqimen and Hengment outlets, with the use of multi-temporal Landsat images is given in Fig. 9.

The same took place since 1979 around Hengli Island and the Jiaomen outlet, which has been narrowed to half its original size at some places (Fig. 10). This caused during the last decades more severe flooding in some of the upper river areas. The river channels were not only narrowing down in the larger outlets, but also in many inner areas.

5. Conclusions

The coastlines extracted from satellite images in 1979, 1990, 2000 and 2003, as well as from topographic maps in 1966 and 2004, were overlaid to establish the coastline changes in the Pearl River Estuary, China. The main conclusions were summarised as the following:

1. The most obvious coastline changes since 1966 occurred at the Nansha area and Shekou peninsular. The former mainly due to sedimentation and reclamation land in the estuary, while the latter mainly result from construction of harbour and filling for highway.
2. One of the most important impacts of coastline change was narrower and longer of the river channels in the estuary, due to the sedimentation and reclamation in the outlets area. The result is more severe flood in the upper river area.

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