SATELLITE MONITORING OF THE DYNAMIC ENVIRONMENTAL CHANGE OF THE ACTIVE YELLOW RIVER DELTA, CHINA

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ABSTRACT

This paper firstly *reveals* a comprehensive macro-evolution of a large river delta by remote sensing. An integrated approach of satellite remote sensing and geographic information system techniques has been employed to survey and monitor the contemporary processes and the dynamics of the active delta (after 1976), the most rapidly changing portion of the Yellow River Delta, China. The main source of data is the Landsat MSS and TM images (60 scenes or windows) spanning the last nineteen years. This set of multi-temporal data has been selectively scanned, georeferenced, and digitally interpreted under an ILWIS environment to quantify and characterize the dynamic environmental changes during 1976 - 1994. Two major aspects have been presently focused on. The coastal fluvial morphologic changes, including channel shifting change (both banks and channel thalweg), channel geometric change (channel length and width), and channel pattern change, are described. The river outlet changes (x-shift, y-shift, and displacement), together with the coastline change as well as the continent-making rates, are systematically measured. Furthermore, a general discussion on the factors controlling the deltaic morphology and its change is given. This research demonstrates that satellite remote sensing in the context of a GIS is very useful for documenting the time-sequential dynamic environmental changes and analyzing the contemporary processes involved.

1. INTRODUCTION

Satellite sensors are valuable tools for surveying and monitoring the dynamic environmental system. Passive sensor systems, like Landsat MSS and TM, record and measure reflected energy in the visible and infrared portions of the electromagnetic spectrum, in which the majority of spectral information on bathymetric and landform features may be detected, identified, and classified. Remote sensing techniques have been operationized by a number of researchers to derive information on those features which occur within delta and related systems (Noorbergen, 1993; Fan, et al, 1992; Gao, et al, 1991; Robert, et al, 1994; Yang, 1995).

Present-day deltas, such as the active Yellow River Delta, belong to the most dynamic environmental systems on earth. They are ideal systems to study using remote sensing and GIS techniques. Using images with high quality, landform features are readily distinguished and classified. In addition, erosion and accretion features can be well detected and assessed under such favourable factors as low water level, low river discharge, and calm weather condition (Yang, 1995). Thus, the fluvial system and the intertidal area can be examined using the visible portion of the electromagnetic spectrum.

This work was performed during the recent two years as a joint research project between the People's Republic of China and the Netherlands. The main focus of this study is to integrate satellite remote sensing and GIS technologies in order to survey and monitor the contemporary processes and the dynamics of the active delta (after 1976), the most rapidly changing portion of the Yellow River Delta, China.

2. STUDY AREA

The Yellow River, well-known as the cradle of Chinese Civilization, has constructed a huge

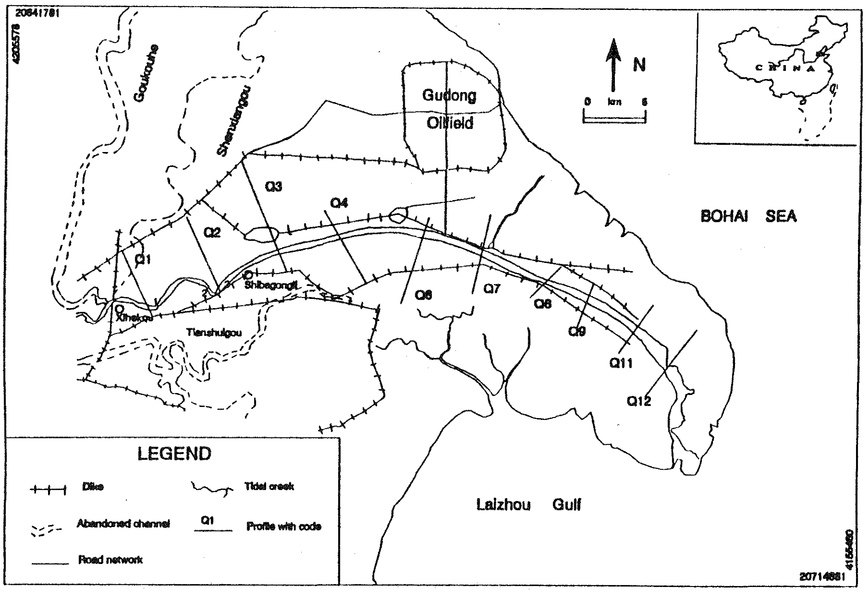

Figure 1 *Location map of the study area.*

Holocene deltaic complex, called the Great Yellow River Delta, with an area of 200,000 km^2. Since 1855, the Yellow River has migrated its main channel more than 50 times and subsequently a present-day delta consisting of at least ten subdeltas or lobes has been developed in the north of Shandong Province, home of the second largest oil field in China. This delta is *unique* for its morphodynamic process. Statistically, the formation of a subdelta (lobe) takes 10 - 12 years (Yang, 1995). While for other large deltas, such as the Mississippi Delta, it generally takes hundreds of years to develop a subdelta.

The active delta refers to the tenth deltaic lobe of the present Yellow River Delta (after 1855) (Figure 1). It is one of the most important oil-exploiting areas in Northeastern China. An active fluvial-dominant (sub)delta, it has been developed since May 27, 1976 when the Yellow River artificially changed its course near Xihekou and ran the Qinshuigou River embouchuring into the Bohai Sea. It is composed of extensively active flood plain (point- and alternating bars and swale formation, active shifting zone, large crevasse splay, and infilled channels), salt marsh, and extremely prograding tidal flat. It represents one of the most dynamic environments in terms of the interaction between human activity and geomorphologic processes. There is an increasing need to understand the morphodynamic trends of this subdelta in order to improve the success of environmental management.

The whole period of development of this deltaic lobe *synchronizes* with the operational age of the earth resources satellites. Extensive availability of Landsat images makes it possible to monitor the full period of the development of the subdelta. The results accomplished is partly a *new contribution* to Earth Sciences.

3. DATA AND METHODOLOGY

An integrated approach combining digital image processing (DIP) and geographic information system (GIS) techniques has been applied for data collection, processing, analysis, and presentation. The main source of data is the Landsat MSS and TM images (60 scenes or windows) spanning the last 19 years (1976-1994). About 17 digitally scanned images, together with three (1/4) windows of TM CCT data (1992, 1993, and 1994), have been carried out a standard procedure of digital image processing aiming to facilitate the subsequent interpretation work. GPS measurements from the field, combined with the information of the master map, are employed for the geometric correction. The strategy chosen here was to correct one image, i.e., the enhanced false colour composite image Y92 (April 11, 1992, Landsat 5 TM) as the master map. Then the corrected Y92 scene was used as the reference for image-to-image registration for all other images. The subsequently (digitally) systematic interpretation was performed with the *on-screen digitizer* program under an ILWIS* environment. With the program *Change Window*, map scale can be enlarged up to 1:3,500 for the images with a 30 m pixel size. It permits an adequate mapping accuracy.

4. RESULTS

The interpretation and analysis have been focused on two major aspects of the dynamic environmental

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* ILWIS is a GIS that integrateds image processing and spatial analysis capabilities, tabular databases and conventional GIS characteristics. It was developed by International Institute for Aerospace Survey and Earth Sciences.

changes, i.e., the coastal fluvio-morphologic change and the river outlet and coastline change.

4.1 Coastal Fluvial Morphologic Change

It includes *channel shifting change, channel geometric change*, and *channel pattern change.*

Both banks have been examined separately their shifting and erosion changes. The *north bank* showed extremely unstable by shifting northward and southward alternately during the first 66 months (May 1976 - Nov., 1981). The maximum shifting distance amounted to 6,458 m (northward) within 17 months for Q4. It was becoming *docile* with the declining of shifting rate after 1981. But it still remained a moderate high migrating rate, ranging from -150 to -500 m per year. The *south bank* showed a similar change with the north bank during the first 66 months. The maximum shifting distance amounted to -3,728 m (southward) within six months for Q7. For the stage of 1982 - 1987, it tended to decrease its migrating rate. But it is becoming extremely unstable with the escalating moving rate after 1987. The difference of the shifting change between both banks after 1987 possibly results from the *differential embankments.* The northern embankment is *stronger* than that on the south bank. The *channel thalweg* is examined its change in both the (metric) shifting rate and the all-round spatial arrangement and orientation changes. The lateral shifting of the channel thalweg shows a similar trend in the south bank. The lineament analysis is used to characterize the orientation, sinuosity, and river fluid potential changes.

Some aspects of the *channel geometric change* are examined. The *channel length* shows an increasing trend with an average of 1,650 m per year. But the increment tends to slow down. The channel tends to decrease its *width* and is becoming approximately equal wide as a whole.

Channel pattern changing from braiding, straight, to slightly meandering has been well documented by the accompanying maps (Figure 2). As a whole, the channel bifurcation index[**] tends to decrease, while the channel sinuosity tends to increase. Two major stages can be well defined. The second stage can be further subdivideded, based on the degree of artificial intervention.

Braiding Stage (1976 - 1980): During this period, the river channel system was extremely unstable, showing the most significant change. The channel system changed from *disorderly braiding, well-organized braiding*, to *generally straight.* The channel system became relatively straight, with a decreasing trend of channel sinuosity. The channel bifurcation index tended to reduce and so for the longitudinal profile gradient. The channel stability index[***] shows an obvious decreasing trend, and the channel tended to be more stable.

Straight - Slightly Meandering Straight Stage I (1981 - 1987): During this period, the channel stability index tended to increase, and the channel became less stable. Due to the rapid vertical progration, the river longitudinal profile gradient became much more gentle. The capacity of the flow to transport its suspended bed-load diminished. This resulted in severe silting which caused the channel unstable and successive flooding events (twice within 1987). The situation in late 1986 - 1987 evidenced that the development of the channel entered the stage of *wither* or *decay* under a natural condition.

Straight - Slightly Meandering Straight Stage II (after 1987): As the channel sinuosity was increasing, the channel was gradually changing from straight to slightly meandering straight. The channle as a whole tended to become more stable. Human intervention was highly successful, especially during the first two years (1988-1989), in strengthening the mainstream to improve the capacity of the flow to transport its suspended bed-load. However, this may maintain the actual running state of the channel for several years, on the long run, a well-organized (artificial) diversion has to be carefully considered.

4.2 River Outlet and Coastline Dynamic Change

The temporal migrating change of the river outlet is presently examined (Table 1). The outlet *displacement*, a scalar without direction, represents the distance between two outlets. The outlet *shift*, a vector with the direction (negative value means a westward shift for *x-shift*, or a southward shift for a *y-shift*), characterizes the migrating change over

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[**] *Bifurcation index* is the ratio of total branching channel(s) length to the length of the river axis.

[***] *Channel stability index* = $B^{1/2}/M$, where B is the width of main channel, and M is the average depth of river channel.

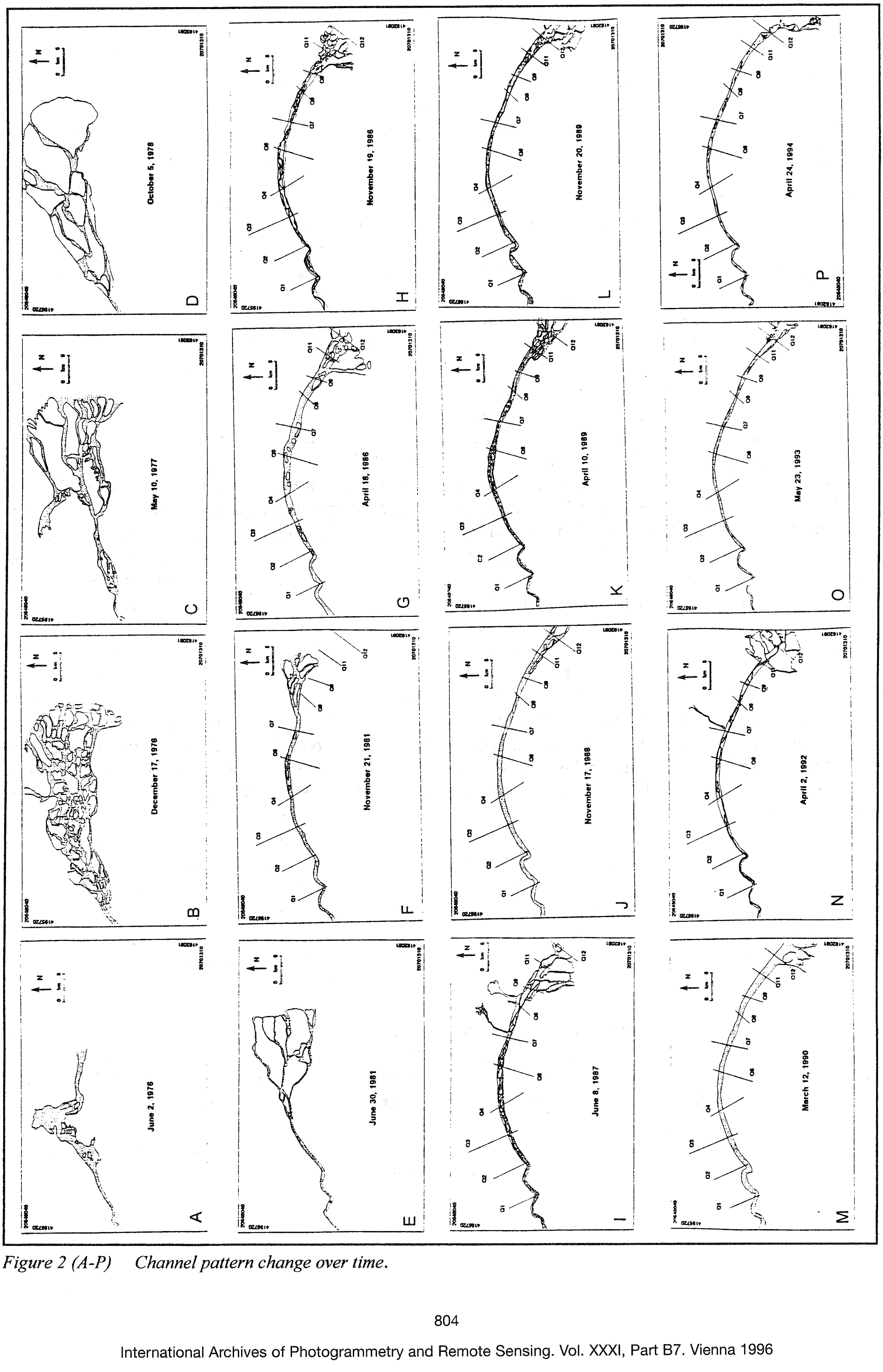

Figure 2 (A-P)   Channel pattern change over time.

selected directions.The *X-shift* generally shows an eastward shifting over a total distance of 29,380 m. The decreasing eastward shift shows that the increment of channel length is slowing down. The *Y-shift* generally displays a southward migration, with a total shifting distance of 13,441 m. It exhibits a dwindling southward shift. As a whole, however, the outlet displacement generally tends to increase its migrating distance.

Table 1 *Statistics of river outlet migrating change over time.*

Nr.	Time	Outlet displacement(m)	Outlet shift		Outlet azimuth(°)
			X-shift	Y-shift	
1	06-02-76	reference point			95
2	12-17-76	8645	8350	-2240	83
3	05-10-77	2961	2380	1761	98
4	10-05-78	12173	-6470	10311	62
5	06-30-81	12474	4550	-11615	61
6	11-21-81	7439	7310	1379	76
7	10-05-84	11241	6390	-9248	115
8	04-18-86	10986	-9520	-5482	184
9	11-19-86	2445	410	2410	178
10	06-08-87	3924	3910	327	192
11	11-17-88	6946	6910	-705	115
12	03-09-89	1597	-1580	230	129
13	04-10-89	1354	740	-1134	115
14	11-20-89	3064	2640	-1556	135
15	03-12-90	3148	-40	-3148	165
16	04-02-92	9147	-2510	8796	65
17	11-12-92	9046	-290	-9041	137
18	05-23-93	5860	840	5799	117
19	11-23-93	4356	3210	-2944	123
20	04-24-94	8643	-7630	-4061	195
21	07-24-94	11867	9780	6722	102

For non-single river outlets, we choose the outlet of the dominant channel.

The *coastline* is carefully mapped from about 12 selected images, based on a number of rules (Yang, 1995). The layouts are illustrated in Figure 3. The deltaic area and the coastline length generally tend to increase. The deltaic area increased at average of 22 km^2 per year for the period of June 1976 - April 24, 1994. However, the increment of deltaic area tends to decrease. For the stage of June 1976 - Nov., 1981, the yearly increment averaged 36 km^2. It was the most important delta-developing stage. During the stage of Nov. 11, 1981 - Nov., 1988, the average increment amounted to 27 km^2 per year. While after 1988 (till April 1994), the deltaic area increased at an average of 2 km^2 per year. The deltaic lobe showed an accelerating migration (Figure 3III).

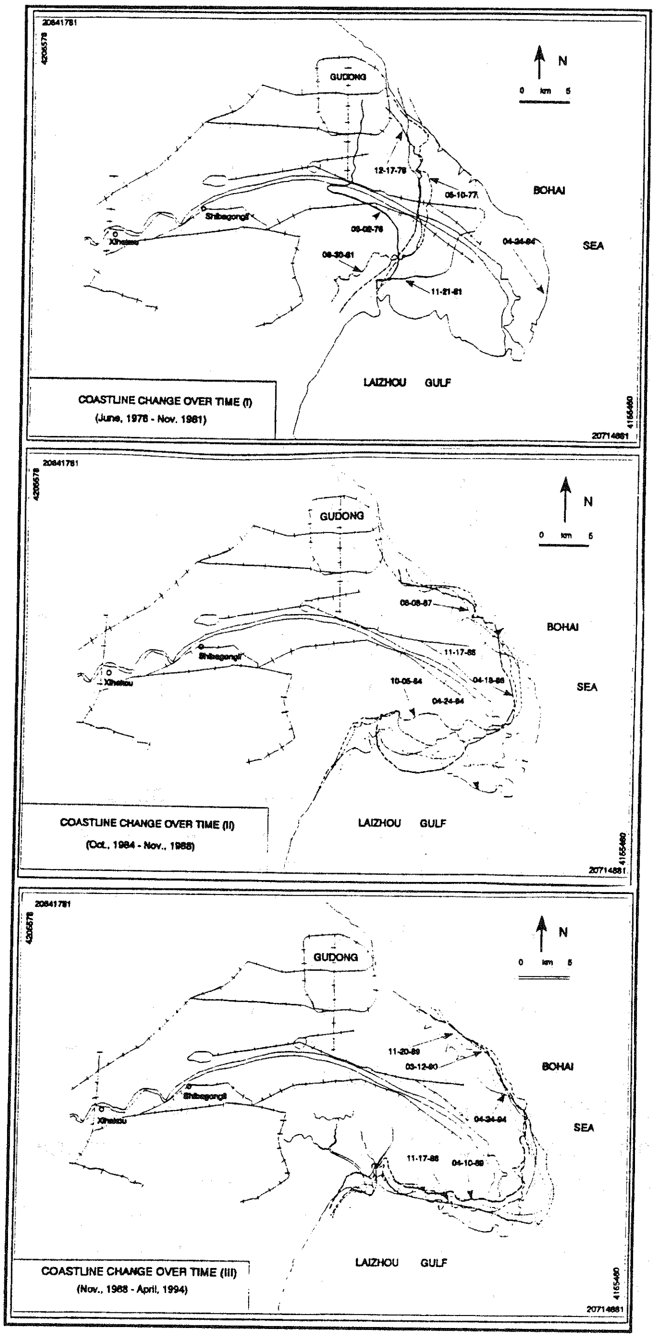

Figure 3(I-III) Coastline change over time.

5. DISCUSSION

This sector intends to provide a general discussion on the factors controlling the deltaic morphology and its change. Those factors include aspects of hydrologic, marine hydraulic, geomorphological, geological, climatical, vegetation and land use, and human activities. Since most of those are not well understood, we do not intend to discuss them further. Instead, several selected problems are presently focused on.

As the marine actions are relatively weak, the active delta can be doubtless classified as a fluvial-dominated delta. *Linear fit analysis* shows that the general change trends of the channel length and deltaic area are highly *synchronous*. The position change of the river outlet determines the configuration of the delta. As the yearly total amount of the sediment discharge decreases, the increment of the channel length tends to decrease, and also for the increment of the deltaic area. As the action of the fluvial process declines, the prograding of the (front) sand bar and the coastline tends to slow down. Marine actions, however, are becoming more important, particularly when the river channel was in dry. For example, in 1992, the river was in dry for 150 days (April - August). No sediment load was carried to the delta. Consequently, the mouth sand/silt bar suffered from an escalatingly strong marine erosion. That is why the channel length as well as the deltaic area showed a noticeable loss in 1992.

Human activities, in the form of building of embankments, artificial diversion, channelization, dredging, and pumping of ground fluids, have posed a very important effect on the development of the delta. Before May 27, 1976, a canal of a length of 8.75 km, together with about 95 km embankments, has been constructed for the latest artificial diversion project. These embankments have played a significant role in limiting the channel shift as well as bankful flooding, and the guiding of the prograding orientation of the delta. Since 1988, an intensified dredging programme has been carried out around the river mouth. The development of the mouth channel has been effectively controlled, especially during the first two years (1988 -1989).

The reason for the southward shifting of the river channel (thalweg as well as both banks) , river outlet, and the delta (siltbar) is very complex. Although this southward shifting can be logically explained by the principle of *the Coriolis force*, the involvements of the *marine hydraulic effect*, *the tectonic activities*, and *the differential embankments* should be carefully considered. In the delta, the dominant northeastern-oriented wind tends to transport silts and sands southward. Statistically the strong tidal currents move southward, which can contribute to a dominated southward transports of silts. Recent study shows that the southern part of the present Yellow River Delta is a tectonically depressing area with an average subsiding rate of 4.2 - 8.3 cm per year (Li, 1993), which surely favours the southward shifting of the delta (channel, mouth siltbar). Considering that most of the oilfields are in the north of the actual channel, the embankments consequently would have to be *stronger* on the north than that in the southern bank. As a result, the northward shifting of the north bank is relatively stopped compared to the southward shifting, which may affect the shifting change of the channel thalweg.

6. CONCLUSIONS

This study firstly *reveals* a comprehensive macro-evolution of a large river delta, the active Yellow River Delta, by integrating multitemporal image data with field observations. This delta, developed initiately since May 27, 1976, has displayed a very complicated environmental changes, both in fluvial-morphodynamics and coastal dynamics. Since 1986, the tenth year of running, the present river channel has entered a stage of *wither* under a natural condition. It is the human intervening that maintaines the actual running state of the river course up to now. However, on the long run, an artificial divertion has to be carefully considered and carried out. The results demonstrate that satellite remote sensing in the context of a GIS is very useful for documenting the time-sequential dynamic environmental changes and analyzing the contemporary processes involved.

7. ACKNOWLEDGMENTS

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8. SELECTED REFERENCE

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