STUDY ON THE COMPUTER DYNAMIC SIMULATION OF THE YELLOW RIVER DELTA ENVIRONMENTAL EVOLUTION

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Abstract The Lower Yellow River is the famous "suspended river" for its silt sediment, and the Yellow River Delta (YRD) is one of the most active delta in the world because the river tail changes its course very frequently. In our research, we applied the Geographic Information System (GIS) and remote sensing to geo-analysis and simulated the environmental evolution of the Lower Yellow River and the Delta. The aim of our research is to try to reveal the delta evolutionary rule, to simulate the environmental evolution procedure and to forecast the future development of the Yellow River Delta.

1. Looking back the developed history of the Lower Yellow River and its Delta.
2. Establishing the Digital Elevation Model (DEM), and analysing and researching the silt depositional situation of the Yellow River Delta.
3. By designing the special computer simulation and display software, establishing the computer dynamic simulation system, and reproducing the historical evolution of the river courses and coast lines from B.C. 2278, From 1853 and from 1934 to present in the Yellow River Delta area.
4. Analysing the vegetation evolution from 1855, implementing the quantitative research, and forecasting the future development.

1. RESEARCH AREA

The Lower Yellow River is a famous river for its massive silt. Due to the silt sediment, the river bed is rising quickly every year. More and more, the river course has been in the instant situation. From B.C. 2278, the Lower Yellow River has always been in the victim circle of "sitting up - rising - extending - cleaning route".

The Yellow River Delta (YRD) studied in the paper is the Yellow River New Delta which begun in 1955 and burnt at Tongwanzhuang. The range is E 115°15'-119°13', N 37°30'--38°10'. The area is about 5,506 km². YRD is located in North-temperate, semi-moist and monsoon climate zone. There are a smooth terrain and a very different kind of climate. The continentality of the delta is 0.65.

The Yellow River is the main river in the area. Every year, the Yellow River carries 10 to 12 hundred million tons of silt to the area. 2/3 of the silt deposits the delta area. So the delta is expanded rapidly.

11. ANALYSIS OF THE DEPOSITIONAL STATE OF THE DELTA

1. The Structure of the Yellow River Delta

(1). The Delta Deposition

Based on the delta deposition, YRD is formed by the overlay of the different sub-delta deposits which were produced by the swings of the river tail in the different periods. These sub-delta deposits are as follows:

a. Yanshao-Xiaobinzhao sub-delta (1855 -- 1904)
b. Yanshao-Sipingzhen sub-delta (1904 -- 1929)
c. Ninghai-Xinhuanghe sub-delta (1929 -- 1934)
d. Tiexihuou sub-delta (1934 -- 1938, 1947 -- 1953)
e. Shexingou sub-delta (1934 -- 1953)
f. Diakouhe sub-delta (1953 -- 1976)
g. Qinshihaiou sub-delta (1976 -- present)

(2). The Different Depositional periods of the Delta

From the point of view of the depositional sequences, we can find that the present YRD is composed of two period delta deposits (one is 1855 to 1934, the other is 1934 to present) in a proper order based on YRD.

The continuous deposition makes the delta develop rapidly from south-west to north-east and form the highest fan-shaped terrain. The river tail swings (on the apex of Ninghai) continues forming two new fan-shaped areas beside the old fan-shaped area. They composed the main frame of the new delta. After 1934, the Yellow River started to build the newest fan-shaped delta area. Its apex is in Tumen. At present, human activity is acting on the newest delta intensely. So, we can see some anomalous phenomena, for example the elevation changes suddenly near the river and its courses.

2. Digital Elevation Model (DEM)

(1). Terrain

YRD is formed by the overlay of the many sub-deltas which were built by the swings of the river tails in different terms. The terrain characteristics of the delta is:

a. The distribution of higher areas is along with the Yellow River and the old river courses. They extend in the radiation state.
b. The lower areas distribute on between natural high areas or the brink of the delta.
c. The delta terrain is very smooth and inclines slowly from the delta apex (near Ninghai) to the shore.
3. Analysis of the Depositional Situation

(1). The Silt Sediment of YRD

By analyzing the present terrain of YRD, we found:

a. There exists about 1/3 delta area in which the elevation is lower than two meters, this is the area of the smoothest terrain.

b. The area where the elevation is higher than nine meters is also smooth, although it is not as smooth as that of the area where the elevation is under two meters.

c. The area where the elevation is between six and nine meters is more complicated in the terrain.

d. The area where the elevation is between two and six meters is the most complicated in the terrain.

Our explanations of the above phenomena are as follows:

a. The area where its elevation is under two meters is in the range of the marine power action. The depositional silt within the area is transported and deposited again. The result is to make the terrain become smooth gradually.

b. The area where its elevation is above nine meters was formed before 1955. The long-time action (including natural and factitious action) has changed the terrain into the smooth terrain.

c. The area where its elevation is between six and nine meters was formed between the years of 1955 and 1934. Because the formed time is less than that of the former, the terrain is more complicated than that of the former.

d. The area where its elevation is between two and six meters is the most unstable area in which the Yellow River tail flows affecting the area and the silt sediment is more evident. So the terrain in the area is the most complicated.

(2). Estimation of the Silt Sediment amount from 1855 to 1934

It was estimated, between 1855 and 1934, that the area above zero meter elevation increased 208 km² in YRD. The annual average increment is 25.5 km². In this period, the volume of the delta deposit increased 85.25 hundred million m³. The annual average increment is 1.07 hundred million m³.

(3). The Calculation of the Silt Sediment Amount since 1954

The Yellow River tail flows into the Bohai sea first by Shenxian River (before 1904), then by Diaoxiu River (before 1976) and now by Qingshui River since 1953.

Chart 1. The change of the silt depositional amount

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Increased area</td>
<td>km²/year</td>
<td>17.5</td>
<td>25.5</td>
<td>36.5</td>
</tr>
<tr>
<td>Annual increment</td>
<td>km²</td>
<td>90.0</td>
<td>102.5</td>
<td>127.5</td>
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<tr>
<td>Increased volume</td>
<td>m³</td>
<td>1.07</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Annual increment</td>
<td>m³/m²</td>
<td>125.0</td>
<td>125.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Silt amount</td>
<td>m³/m²</td>
<td>119.11</td>
<td>108.25</td>
<td>108.25</td>
</tr>
<tr>
<td>annual silt amount</td>
<td>m³/m²</td>
<td>11.71</td>
<td>8.40</td>
<td>8.40</td>
</tr>
<tr>
<td>Increased area by each</td>
<td>m³/m²</td>
<td>2.35</td>
<td>2.43</td>
<td>2.43</td>
</tr>
<tr>
<td>10 m³ (ton/m³)</td>
<td>0.051</td>
<td>0.096</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased volume by each</td>
<td>m³/ton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 m³ (ton/m³)</td>
<td>0.051</td>
<td>0.096</td>
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Comparing with the DEM data among 1954, 1972 and 1984 in chart, we can get some conclusions:

a. From 1954 to 1971, the area above zero meter elevation increased 407.6 km². The annual increment is 27.5 km². From 1972 to 1984, the area increased 283.1 km². The annual increment is 20.4 km². The latter is less than the former. The amount between 1955 to 1934 is less than the former but more than the latter. This change may mean the change of the river silt.

b. From 1954 to 1971, the total silt amount in Lihe hydrologic station is 119.11 hundred million ton. The annual amount is 11.71 hundred million ton; From 1972 to 1984, the total silt amount is 108.25 hundred million ton, the annual amount is 8.40 hundred million ton. The latter is less than the former.

c. From 1955 to 1934, the annual increment in volume is 1.07 hundred million m³; From 1954 to 1971, the annual amount increment is 0.90 hundred million m³. From 1972 to 1984, the annual increment is 0.81 hundred million m³. The change in volume is first decreasing 0.47 hundred million m³ and then increasing 0.21 hundred million m³.

d. The more the silt amount was deposited, the more the increment in area is, but the less the increment in volume is. The cause which bestow these phenomena may be relative to the water amount and the total silt amount each year.

(4). Analysis of the Depositional Situation of the Subaqueous Delta

The Yellow River Subaqueous Delta is the natural extension of YRD under sea level. It is the important part of YRD. The area between -25 to 0 meter is about 0.07 km².

Chart 2. Silt depositional distribution of the Subaqueous Delta

| elevation | area | volume | terrain status | volume each km² |
|-----------|------|--------|----------------|----------------|----------------|
| -25.0 to -25.0 | 74.55 | 0.04 | 0.89 | 0.59 |
| -25.0 to -22.5 | 842.79 | 2.05 | 1.83 | 2.43 |
| -22.5 to -20.0 | 855.50 | 4.00 | 0.47 | 4.68 |
| -20.0 to -17.5 | 603.79 | 0.90 | -0.26 | 7.17 |
| -17.5 to -15.0 | 605.60 | 8.70 | -5.32 | 9.72 |
| -15.0 to -12.5 | 777.75 | 9.44 | -1.07 | 12.14 |
| -12.5 to -10.0 | 888.79 | 13.09 | 0.09 | 14.75 |
| -10.0 to -7.5 | 434.69 | 9.30 | -5.43 | 17.10 |
| -7.5 to -5.0 | 375.79 | 7.35 | -5.07 | 19.05 |
| -5.0 to -2.5 | 300.00 | 7.76 | -1.2 | 22.13 |
| -2.5 to -0.8 | 407.75 | 10.01 | 2.95 | 24.56 |

Based on the subaqueous delta DEM data, we have got some results (see chart 2). Let's analyze the data in chart 2. We can obtain following results:

a. The silt sediment of the subaqueous delta is deposited within -20 meter isolithe.

b. Most of the silt sediment is concentrated in the range from -10 to 0 meter.

c. The silt sediment decreased very quickly between -15 to -10 meter.

d. The isobath which the elevation is -10 meter may be an important curve. The silt depositional characteristics may exist some evident difference within -10 meter area for different times of the subaqueous delta.

III. THE RIVER COURSE AND COASTLINE EVOLUTION

1. Evolution of the Lower Yellow River Courses

Dike burstings of the Lower Yellow River took place over 1500 times, and large burstings also took place more than 25 times since B.C. 2278. After 1955, the Yellow River
abstracted the Yellow River, dyke burstings have taken place over 50 times, and large burstings and course changing was 12 times.

2. Coastline Evolution in YRD Area

Coast zone is one of the most active geographic units on the earth surface. Some scientific researchers have studied the migration of the Bohai Gulf from Pleistocene epoch by researching the drilling data and analyzing MSS, TM satellite image.

3. Dynamic Display System of the River Course and Coastline

Evolution in the Lower Yellow River and Its Delta

From ancient time, the migration of the Yellow River took place incessantly, especially in the lower reaches and river mouth area. By studying the migration of river courses and coastlines, we can understand the historical change and change pattern. Lately, we have done some studies which is how to describe dynamic changes of river courses and coastlines with computer and graphic software system. So we have developed "the Dynamic Display System of the River Course and Coastline evolution in YRD (DESYRD). The results indicate that the dynamic display software is a useful tool not only for reproducing the dynamic evolution on the computer screen about some natural phenomena, but also for studying the evolutionary model and forecasting the further development.

The Dynamic Display System includes three parts:
  a. System specification
  b. Dynamic display subsystem of river course and coastline evolution in the Lower Yellow River area (LYRA). (from B.C. 2278 to 1976)
  c. Dynamic display subsystem of river course and coastline evolution in the New YRD (NYRD). (from 1855 to 1987)

Fig 1 and Fig 2 demonstrates the data processing and the procedure of system execution.

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Begin

Specification of DESYRD

Specification of LYRA

Specification of NYRD

Data input of LYRA

Data input of NYRD

Dynamic simulation display

Dynamic simulation display

End sub-system

End

End sub-system

Fig 2. Execution diagram of DESYRD
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IV The Change of the Vegetation Distribution in YRD during Recent 30 Years

On the basis of the maps of vegetation distribution in YRD, which we made with 3 times data of 1955, 1972 and 1985, we analyzed the changes of the vegetation distribution during 1955 -- 1985 in the area.

The vegetation in YRD is classified to 10 types, according to the sequences which appearance from the seaside to the inland, they are : 1) mud flat; 2) salt lick; 3) reed mixing with some salt-enduring grass; 4) reed mixing with some salt-enduring shrub; 5) salt-enduring grass-shrub; 6) salt-enduring grass-arboret; 7) halophyte; 8) forest; 9) rice field; 10) cultivated land (including the lands of corn, cotton, wheat and some artificial land).

Comparing the 3 maps, we found some evident changes in YRD area:

1. The forests and salt-enduring grass-arboret tend to be on the decreasing:
   a. In 1955 there were some large-area forests located in the north part of the Yellow River, especially gathered in the area was higher than 5 meters. The salt-enduring grass-arborets located along the two sides of the Yellow River course which wasted lately, were parallel to coastline.
   b. In 1972, the large-area forests located in inland area had disappeared, only few remained near the places where Yellow River changed its course in 1954. The range of salt-enduring grass-arborets located near coastline became to be narrow.
   c. In 1985, the forests had remained only in some scattered lands, along the course of the Yellow River wasted in 1964 and in 1976 of northeast of the YRD there were forests in belt area.

The salt-enduring grass-arborets had disappeared on the whole, they were taken place by reeds, salt steppe or artificial lands.

2. The salt lick tends to be on the increasing:

Contrasting to the decreasing of the forests, the salt lick tends to be on the increasing in YRD. There are two types of salt lick in the area. One type is large-area
and located in the northeastern and southeastern of the YRD. Another type is in scattered lands, the former is due to its location close to seashore and is influenced by the sea. The latter is scattered from seashore to inland. Comparing the maps of 1955 and 1985, we found the latter type in 1985 is clearly more than in 1955 in the inland in cultivated area.

(3) The range of artificial land is expanded and the inner boundary of the natural vegetation is moved forward the seashore.

Due to the continuously expanding in YRD since 1955, more and more farmers come to YRD to open up the virgin soil, and the cultivated land area is continuously expanded. So the inner boundary of the natural vegetation is gradually move to the northeast of the YRD. Comparing with 1955, the newly expanded artificial lands mainly located over the fan-shaped area ranged from the course before 1976 to the course before 1984, the elevation is higher than 3 meters in the area.

(4) The distribution range of the reeds tends to be on the increasing:

a. In 1955, the reeds were mainly located in the part close to seashore of the course which went in 1953, and in the northeast of the YRD.

b. In 1972, the range of the reeds was expanded to the course went in 1994 and the lower reaches of the new course at that time.

c. In 1985, the range of the reeds was further expanded to the areas close to seashore of the current course. In the meantime the salt-enduring grass-shrub and salt-enduring grass-shrub were gradually decreased and on the whole disappeared in the same area.

(5) The distribution in the two side of northwest and southeastern of the YRD is stable on the whole.

Contrasting finely with the changes of the vegetation in the northeast of the YRD at the same time, the vegetation located in the northwest and in the southeast of the YRD are stable in the main, although the range was more or less changed. According to the pattern of the distribution of the vegetation over the two areas, the appearing sequences of the vegetation types, in both areas are the mud flat → salt-enduring vegetation → cultivated lands from the seashore to the inland, are not changed. Especially, it is not influenced by the change in course of the Yellow River for 30 years in the northeast of the YRD and for 20 years in the southeast of the YRD. So the inner boundary of the natural vegetation in both areas are stable near the range which elevation is about from 3 to 4 meters, where is the upper limit influenced by the storm surge.

So we can found the summary knowledges of the follow:

(1) The basic characteristics of the distribution of the vegetation are belts and zoning.

The belt means that the appearing sequence of the vegetation is mud flat → halophyte vegetation → salt-enduring vegetation → cultivated land, through the ranges and the types are more or less changed.

The zoning means that there are differences between the northeast with northwest and southeast in the YRD, the former one is mainly covered by reeds due to the lower elevation and close to the current and wasted courses of the Yellow River, and in the northwest and in the southeast of the YRD, in the both areas the natural vegetation are halophyte and halodurable plant.

(2) the dominant(leading) factors which change the ranges of the vegetation in YRD are the swings of the Yellow River tail and the human activities.

Due to the swings of the Yellow River tail were limited in the northeast of the YRD during the recent 30 years, the vegetation range was evidently changed in the area, the dominant species of the bio-community is the reed. In contrasting with the changes in the area, the natural vegetation in the northeast and in the southeast of the YRD, which coesinlites are stable for a long time, their ranges are not to be changed.

The human activities caused the range of the cultivated land to expand and result in the decreasing of the forest during past 30 years.

(3) The succession of the natural community in the YRD

The leading factors limiting the range of the vegetation in YRD are soil moisture and soil salinity, and the climate in YRD is not clearly changed in past 30 years. So the succession of the natural community is mud flat → halophyte → salt-enduring plant → salt-unenduring plant in the YRD. In the lower and flat areas, likely in the petroleum of the YRD, the dominant species is the reed, and in the other areas, the dominant species are halophyte and halodurable plant.

V CONCLUSION

Based on the discussion above, we can reach following conclusions:

a. The great silt sediment results in the river course and coastline migration. On the other hand, the river course and coastline migration results in the delta forming, evolution and development. So for exploiting YRD, understanding above situation is the key.

b. DEM can reflect the different situation of the different silt depositional order to some extent. Because the different sub-deltas have different depositional characteristics, the syntheses of the characteristics constructs the terrain boundary among these different sub-deltas.

c. The ranging of the vegetation in YRD have changed very evidently in the past 30 years. The main factors caused the change are the swings of the Yellow River tail and the artificial activities.

d. The swings of the Yellow River tail also is the main reason of other environmental factors’ development.

REFERENCES

2. Chen Feng. The analysis and application of the Micro-terrain DEM for the Yellow River Delta, Regional Study and Exploitation Special Issue, 1990
4. Pong Jiaochan and Si Shuheng. Evolution of the Yellow River Mouth, 1979
Fig. 3. Micro-Terrain DEM in YRD (Elevation difference 0.25 meter)
Fig. 4. DEM of Subaqueous Delta in YRD

(1) Sub-system of LYRA (from B.C. 2278 to present)

(2) Sub-system of NYRD (from 1855 to present)

Fig. 5. Dynamic display system of river course and coastline evolution in LYRA and NYRD

Fig. 6. Vegetation change of YRD (from 1954 to 1985)