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INFLUENCE OF VARIATION OF WATER-SEDIMENT PROCESS ON THE COASTAL LINE IN THE YELLOW RIVER DELTA

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Abstract: Coastal line erosion and delta area decrease are becoming a hotspot for governments and scientists in the world. The trend and speed of forming land restrict the economic development and ecological environment improvement in delta area. According to coastal line changes during the high tidal periods of l976,1986,1992，1996，1997,and l998，the trend of progradation and erosion of the Yellow River delta was studied. The results show that the coastal 1ine progradation and erosion are proceeding simultaneously，and generally the formed land area in the delta is decreasing. The analysis results of water discharge and sediment load from 1950 to 2001and their relation to the formed land area show that when sediment load is 245 $\times 10^6$t， delta the Yellow River delta will arrive rough balance of progradation and erosion.

Key words: Variation of water and sediment discharge, Coastal process; The Yellow River delta

Coast erosion and delta area decrease, which are mainly caused by the reduction of sediment discharging into the seas due to human activities, have recently been a focus of governments and scientists in the world. The trend and velocity of forming land restrict the economic development and ecological environment evolvement in delta area. The Yellow River is celebrated for its low water discharge and high sediment discharge and its coastline averagely elongates seaward 25km per year. What's more, due to the change of natural factors and aggravation of human activities, the coming water-sediment of the Yellow River mouth take gigantic change in recent years, which can be seen from the aspects of water-sediment's decrease and aggravation of zero flow. The Yellow River mouth is a stream mouth with weak tide, the coming water-sediment play a important roll on the coast evolution. Hence, studies of influence and its process on coast evolution caused by the reduction of water-sediment have vital meaning not only in the theory but also on flood control and sustainable development of the delta.

1. DATA AND STUDY METHOD

The following data is taken in this paper: water-sediment situ data of Lijin hydrometric station in Yellow River from 1950 to 2000; 1976,1986,1992,1996−1998 satellite remote sensing images of Yellow River Delta; 1976,1986,1992,1996 offshore bathyorographic maps of Yellow River mouth with the scale of 1:100000; 1996−1998 offshore bathyorographic maps of Yellow River mouth with the scale of 1:25000; 1996−1998 topographic maps of Yellow River channel with the scale of 1:25000.

The study area of this paper is between east longitude 118º15′−119º50′ and north latitude 37º30′−38º20′. This area is the total scope and beach of the Yellow River delta. The high-tide shorelines of various years are taken to comparison.

Based on various kinds of situ data, remote sensing image and analysis of the high-tide shoreline, deposition and erosion of the whole Yellow River delta are measured and the trend of the whole delta area is investigated in this paper. According to the analysis of coming water-sediment characteristics, the relationship between forming land area and water-sediment is studied. Meanwhile, with the study before, the threshold value of water-sediment when the Yellow River delta tends to dynamic balance is discussed.

2. VARIATION FEATURE OF WATER-SEDIMENT OF YELLOW RIVER

2.1 WATER-SEDIMENT INTERANNUAL VARIATION

2.1.1 Total discharge

The Yellow River is characterized as a river that has low water discharge and high sediment discharge and has a great difference in the flood and dry season. According to the statistics of the water-sediment data of Lijin hydrometric station from 1950 to 2000, the mean annual runoff of the Yellow River mouth is about $338.2\times10^8m^3$ and the mean annual discharge is nearly $1123m^3/s$, the mean annual sediment discharge is about 8.49×10^8t and the mean annual sediment concentration is up to $25.66kg/m^3$.

2.1.2 Interannual distribution

The interannual distribution of water-sediment is terribly uneven (shown in Fig.1). Among the flow discharge data, the biggest flow discharge is $973\times10^8m^3$ (1964), the lowest one is about $18.61\times10^8m^3$(1997), the ratio between them is nearly 52.28:1. Meanwhile, the highest sediment discharge is 21×10^8t (1958), and the lowest is 0.164×10^8t (1997), the ration between them is up to 128.05:1 (Fig. 2). The highest yearly mean sediment concentration is $48kg/m^3$ (1959), the lowest is 8.84 kg/m^3 (1987), the mean annual sediment concentration is about 22.2 kg/m^3.

2.1.3 Trend of water-sediment change per ten years

Seen from the fifty years water-sediment data, it can be concluded that the flow discharge in the 1950s and 1960s was abundant and reduced significantly in the 1970s. The mean annual discharge of Lijin station was about $480.5\times10^8m^3$ in the 1950s, $501.2\times10^8m^3$ in the 1960s, $311.2\times10^8m^3$ in the 1970s, $286\times10^8m^3$ in the 1980s, $132.56\times10^8m^3$ in the 1990s, respectively. According to the data in Table 1, the trend chart was obtained as Fig.4 from which we can see that the flow discharging into the sea decrease obviously.

Likewise, the trend of sediment change can also be acquired. The sediment discharge decreased significantly in the past years. The mean sediment discharge was nearly 13.19×10^8t in the 1950s, 10.89×10^8t in the 1960s, 8.98×10^8t in the 1970s, 6.29×10^8t in the 1980s, 3.58×10^8t in the 1990s, respectively. From the trend chart (Fig.5 and Fig.6), it can be concluded that the sediment discharge decreased significantly in the past fifty years, and the sediment concentration changed lowly.

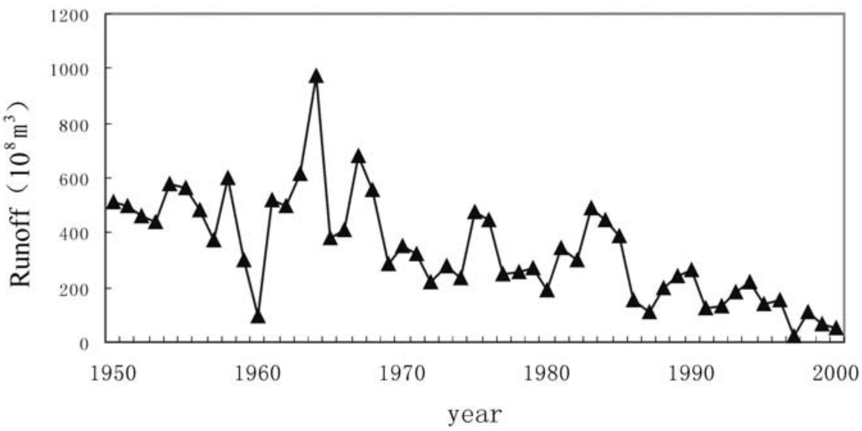

Fig. 1 Mean annual discharge hydrograph in Lijin hydrometric station

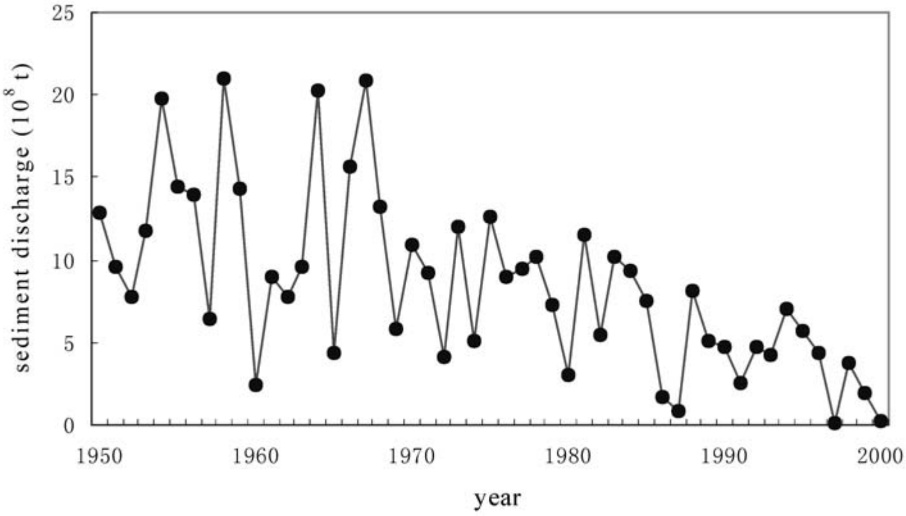

Fig. 2 Mean annual sediment discharge hydrograph in Lijin station

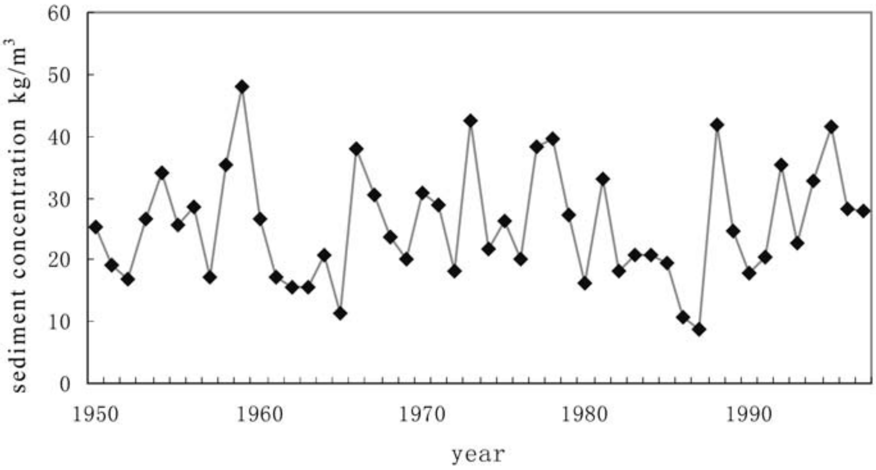

Fig. 3 Mean annual sediment concentration hydrograph in Lijin station

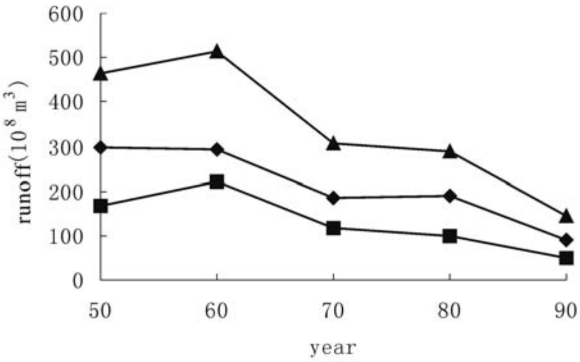

Fig. 4 Mean discharge hydrograph per ten years in LiJin station

Table 1 Water-sediment feature per ten years in Lijin station （1950-2000）

year	annual sediment discharge 10^8t	annual water discharge 10^8m^3	Mean water discharge m^3/s	Runoff depth mm	Runoff coefficient $m^3/s.km^2$	Maximum discharge m^3/s	mean sediment transport capacity t/s	Erosion coefficient t/km^2	Mean sediment concentration kg/m^3	Maximum sediment concentration kg/m^3
50-59	13.2	480.5	1522.9	63.9	2.03	6929	41.8	1788.8	27.71	101.22
60-69	10.89	501.2	1589.2	66.7	2.11	5879	34.5	1475.4	21.95	77.18
70-79	8.98	311.2	986.4	41.4	1.31	4874	28.5	1197.8	29.35	115.92
80-89	6.29	286.0	901.2	37.9	0.93	4884	20.2	741.2	21.53	81.98
90-00	3.58	132.56	488.6	20.5	0.65	2983	13.2	555.9	28.3	108.2
50-00	8.49	338.16	1123	47.1	1.49			1176.63	25.66	

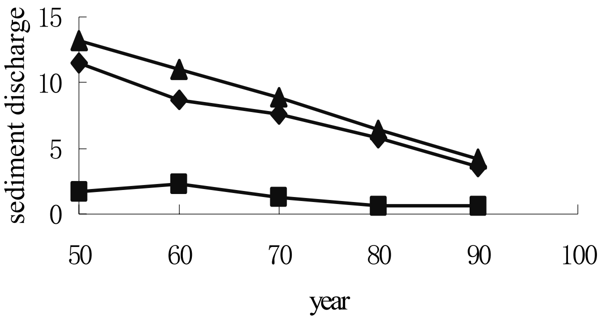

Fig. 5 Mean sediment discharge hydrograph per ten years in LiJin station

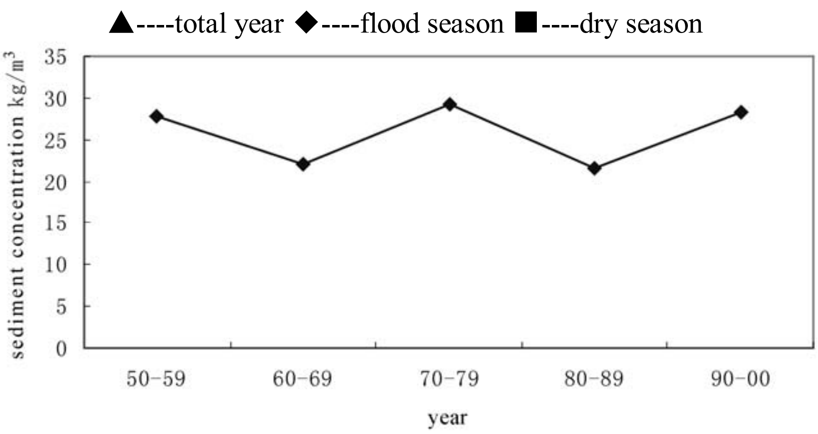

Fig. 6 Mean sediment concentration hydrograph per ten years in LiJin station

2.2 WATER-SEDIMENT VARIATION WITHIN A YEAR

2.2.1 Water variation feature in flood and dry season

According to the statistic of water discharge data from 1950 to 2000 in Lijin station, Table 2 and Fig.7 can be obtained.

Table 2 Mean monthly discharge in LiJin station

Month	1	2	3	4	5	6	7	8	9	10	11	12
discharge $m^3 \cdot s^{-1}$	458	414	602	617	575	542	1441	2302	2182	1869	1168	636
Ratio(%)	3.57	3.23	4.70	4.82	4.49	4.23	11.26	17.97	17.04	14.60	9.12	4.96

It is indicated in the Table 2 that the water discharge was uneven and had obvious seasonal differences. According to the annual values in every month, the biggest flow discharge is in August about 2302 $m^3 \cdot s^{-1}$, the lowest flow discharge is in February about 414$m^3 \cdot s^{-1}$, its ratio between them is about 5.56. The biggest 3 months (August, September and October) water discharge are almost 46.09% of the whole year discharge. July to October is flood season and its discharge is up to 63.55% of the whole year discharge. November to June of next year is dry season and its discharge is about 36.45% of the whole year.

2.2.2 Sediment discharge variation feature in flood and dry season

According to the statistic of sediment discharge data from 1950 to 2000 in LiJin station, Table 3 and Fig.7 can be obtained.

Table 3 Monthly sediment discharge in Lijin station

Month	1	2	3	4	5	6	7	8	9	10	11	12
Sediment discharge $kg \cdot s^{-1}$	1234	1524	5739	7301	6337	7224	50010	102600	77957	42294	16335	3671
Ratio (%)	0.38	0.47	1.78	2.27	1.97	2.24	15.52	31.84	24.19	13.13	5.07	1.14

From Tab.3, it can be concluded that the sediment discharge was more uneven than the water discharge. The biggest monthly mean sediment discharge is in August about 102,600 $kg \cdot s^{-1}$, the lowest is in January about 1234$kg \cdot s^{-1}$, its ratio is nearly 83.14. The biggest 3 months (August, September and October) are about 71.55% of the whole year sediment discharge. The 4 months in flood season are about 84.68% of the whole year. It has more concentrative distribution than the water discharge.

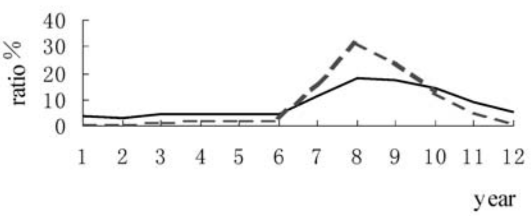

Fig. 7 Frequency chart of runoff and sediment discharge

3. THE CHARACTERISTICS OF YELLOW RIVER DELTA EVOLUTION

3.1 THE WHOLE SHORELINE OF YELLOW RIVER DELTA TAKES SEAWARD TREND

Based on 1976,1986,1992,1996−1998 satellite remote sensing image of Huanghe Delta and comparison of the high-tide shoreline, the evolution of the whole shoreline is investigated. Where the shorelines of 1976,1986,1992,1996 are obtained from the offshore bathyorographic maps with the scale of 1:100000 which are measured by the hydrometric station in Jinan, hydrology and water resource bureau of Shangdong and river mouth, the shorelines of Oct.1996,1997, Oct.1998 are taken from the offshore bathyorographic maps with the scale of 1:25000 which are measured by hydrology and water resource bureau of river mouth and the institute of Yellow River management. After comparison of these high-tide shorelines, it can be found that the shoreline of Yellow River delta are all in seaward trend in the whole from 1976, but it also has some erosion. The area of land above the high-tide line are measured using the method of numerical measurement, the results are given in Table 4.

Table 4 Progradation and erosion of the Yellow River delta from June 1976 to Oct.1998

Time interval	Progradation km^2	Erosion km^2	Net Progradation km^2	Annual net Progradation km^2	Erosion / Progradation	Sediment discharge 10^8t	Annual sediment discharge 10^8t	Water discharge 10^8m^3	Annual water discharge 10^8m^3	Coefficient of incoming sediment $kg.s/m^6$
197606−198606	436.13	59.65	376.48	37.6	0.14	82.62	8.26	3350.3	335	0.0232
198606−199209	280.5	151.89	128.61	21.44	0.54	27.40	4.57	1114.69	185.78	0.0437
199209−199606	200.23	148.36	51.87	13	0.74	21.82	5.46	748.01	187	0.0492
199606−199610	23.95	2.07	21.88	21.88	0.09	4.18	4.18	128.5	128.7	0.0269
199610−199710	0.72	11.16	-10.44	-10.44	15.5	0.31	0.31	38.818	38.818	0.0648
199710−199810	13.54	2.56	10.98	10.98	0.19	3.75	3.75	101.05	101.05	0.1161

From the above table, it can be seen that the shorelines of Yellow River delta in 1976−June,1996 propagated seaward in the whole. The amount of progradation and erosion are about 916.86 km^2 and 359.9 km^2, respectively. The net progradation is 556.96km^2. The evolution of the shoreline is shown in Fig.8.

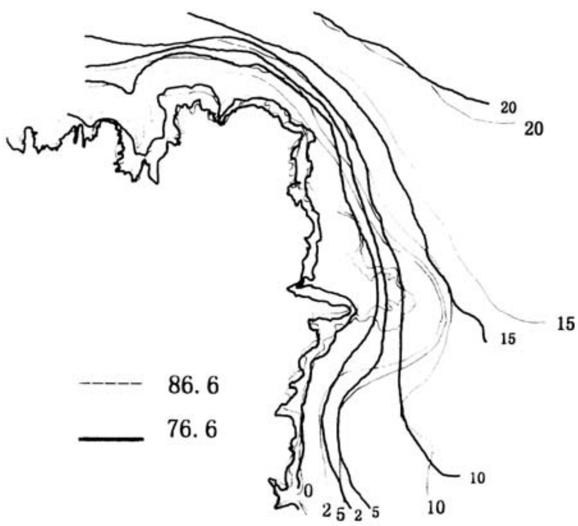

Fig. 8 Shoreline and isobath in the Yellow River delta in 1976,1986

The adjustment projects of river mouth are conducted in the place about 950m above the Qing 8 section in May to July of 1996. after that, the progradation and erosion of Yellow River delta are about 38.21 km^2 and 15.79 km^2 from June1996 to Oct.1998, respectively. The net progradation is 22.42 km^2. Although days of zero flow are high up to 226 in 1997, the whole trend of Yellow River delta are seaward in this 3 years and the annual area of forming land is about 7.5 km^2.

3.2 THE RATES OF FORMING LAND DECREASED IN YELLOW RIVER DELTA

It can also be found from Table 4 that the rates of forming land decreased gradually. From Table 4, we can obtain the following points.

1) The Huanghe delta was in the status of progradation in the 20 years from 1976 to 1996, but the mean annual progradation area were in the trend of gradual descending. The mean annual area of forming land in these 20 years was about 27.85 km^2, in which the mean area of forming land from 1976 to 1986 was up to 37.65 km^2, and the one from 1992 to 1996 is only 13 km^2.

After the adjustment of the river in 1996, the Huanghe delta evolution had the same trend as before, but its rate decreased obviously. The forming land area was up to 21.89 km^2 from June.1996 to Oct.1996, while it was 10.98 km^2 from Oct.1997 to Oct.1998.

2) From 1976 to 1996, progradation and erosion of Huanghe delta existed simultaneously. The ratio between erosion area and progradation area increased gradually, which also indicated the forming land area were decreasing. The ratio was 0.14 from 1976 to 1986, while it was 0.75 from 1992 to 1996.

The delta took the same feature from June 1996 to Oct. 1998, the erosion/progradation ratio was 0.09 from June 1996 to Oct.1996, and the value was 0.19 from Oct.1997 to Oct.1998.

4. THE RELATION BETWEEN FORMING LAND AND COMING WATER-SEDIMENT AND THE CONDITION OF DYNAMIC BALANCE

The Yellow River mouth is a stream mouth with weak tide, its marine dynamics are very weak. Hence, the formation and scale of delta are determined by the coming water-sediment of upper reach. The sediment from the river is origin of the delta (shown in Table 4). From Table 4, it can be concluded that the forming land area and coming water-sediment have a positive correlation relation. 1976−1996, with the gradual decrease of coming water-sediment, the forming land rate was also decrease. The mean annual sediment and flow discharge were 8.26×10^8 t and 335×10^8 m^3, respectively, and the corresponding forming land area reduced from 37.6km^2 to 13km^2. From Oct.1996 to Oct.1997, the coming water-sediment had significant decrease, the flow and sediment discharge were only 38.82×10^8 m^3 and 0.31×10^8 t, respectively, and the delta area reduced about 10.44km^2.

According to the delta area data obtained from the remote sensing images and offshore bathyorographic maps and the results of 1855−1954, 1953−1976 obtained by others (Table 5), Relation chart of the forming land area and sediment load at the Yellow River delta is plotted and the conclusion that the forming land area and coming water-sediment have a positive correlation relation is acquired (Fig.9).

From Fig.9, the relationship between forming land and sediment load can be expressed as $y=3.4008x-8.3189$, its coefficient of correlation is 0.604. Set the forming land as zero, then the sediment load is 0.245 billion t. That is to say, when the sediment load is less than this value, the delta would be eroded, when the sediment load is equal to this value, the delta evolution is in the feature of dynamic balance. This value is very close to the result of document.

Due to limitation of data and no consideration of marine dynamics, this conclusion is preliminary and need further study. Meanwhile, this value is just a threshold of dynamic balance, there is no results on when the delta evolution get the dynamic balance because of the complexity of its evolution.

Table 5 Progradation and erosion of the Yellow River delta from 1855 to June 1976

Time interval	Progradation km^2	Erosion km^2	Net Progradation km^2	Annual net Progradation km^2	Erosion / Progradation	Sediment discharge 10^8t	Annual sediment discharge 10^8t	Water discharge 10^8m^3	Annual water discharge 10^8m^3	Coefficient of incoming sediment $kg.s/m^6$
185506-195307	2340	830	1510	23.6	0.35	704	11	32896	514	0.0131
195307-196312	286	42	244	24.4	0.15	118.67	11.87	4720	472	0.0168
196401-197605	500	166	344	27.83	0.33	133.96	11.16	5028	419	0.02

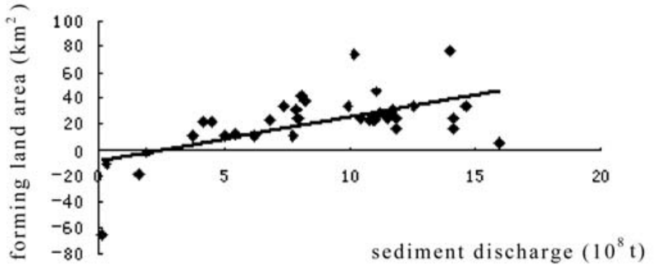

Fig. 9 Relation of the forming land area and sediment load at the Yellow River delta

The threshold of 0.245 billion t is just a mean value. If the flow discharge increase, more sediment would be transported to the sea, then the same coming sediment would cause delta to erosion. Adversely, if the flow discharge decrease, more sediment would silt in the river mouth, the delta area would increase. Hence, under the condition of same sediment discharge, the delta evolution would be affected by the runoff.

5. CONCLUSION

Based on the analysis of above, the following conclusions can be given:

1) From 1950, the mean annual runoff of Yellow river was about $338.2\times10^8m^3$, the mean annual sediment discharge was nearly 8.49×10^8t. The runoff had a descending trend from 1970s, the sediment discharge decreased significantly in the past fifty years and the sediment concentration kept stably. As for the mean monthly discharge, the biggest is in August about 2302 $m^3\bullet s^{-1}$, the lowest is in February about $414m^3\bullet s^{-1}$, its ratio is 5.56. The 3 months biggest discharge (August, September, October) are about 46.09% of the whole year, the dry season (November to June of next year) are about 36.45% of the whole year.

2) The coming water-sediment has a uneven variation within a year. In flood season, the discharge is about 63.55% of the whole year, the sediment discharge is about 84.68% of the whole year. The sediment discharge has a more concentrative distribution than the runoff.

3) The Yellow river delta deposits seaward in the whole, but the forming land are has a descending trend. The forming land area has a relation with the coming water-sediment, it is a positive correlation relation with the sediment discharge. When the coming sediment discharge is equal to 0.245 billion t, the delta evolution keeps in a dynamic balance.

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