VARIATIONS OF RUNOFF AND SEDIMENT FLUXES INTO THE PACIFIC OCEAN FROM THE MAIN RIVERS OF CHINA

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Abstract: This paper presents information on variations of runoff and sediment fluxes into the Pacific Ocean from Chinese rivers during the period 1955 to 2007. The data series are summarized by the annual runoff and sediment loads of 17 representative gauge stations on 10 major rivers flowing to the Pacific Ocean. It is shown that the average annual runoff flux entering the Pacific Ocean from Chinese rivers is about 1,560 billion cubic meters. Over the observed 53-year study period, the runoff flux has presented no evidence of a tendency to change. The mean annual sediment flux carried into the Pacific Ocean is about 1,392 million tonnes and it decreased from 2,087 million tonnes to 575 million tonnes with 4 clear steps over the 53-year study period. This decrease is due to the integrated effects of human activity and climate change.

Keywords: runoff, sediment flux, Pacific Ocean, Yellow River, Yangtze River

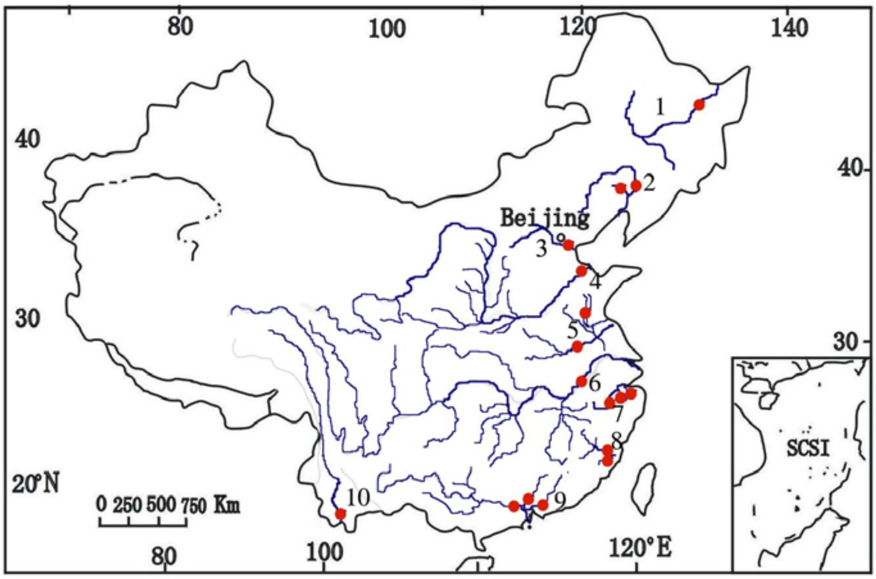
1. INTRODUCTION

There are more than 50,000 rivers with catchment areas over 100 km^2 in China. Of these, 1,600 have a catchment area of more than 1,000 km^2 and 79 have a catchment area of more than 10,000 km^2. The total annual runoff is about 2,700,000 billion m^3 (MWR, 2004). China’s rivers can be categorized as exterior and interior systems. Almost all large rivers in China belong to the exterior river system, which directly or indirectly empty into the Pacific, the Indian and the Arctic Oceans. Because China's terrain is high in the west and low in the east, most of its rivers flow from west to east into the Pacific Ocean, including the Heilong, Liaohe, Haihe, Yellow (Huanghe), Huaihe, Yangtze (Changjiang), Minjiang, Pearl River and Lancang Rivers. The area drained by these rivers belongs to the Pacific catchment area, and covers 5.445 million km^2, or 56.8 % of the country's total mainland area.

Of the 10 rivers emptying into the Pacific Ocean, the Songhua is a tributary of the Heilong river, which is called the Amur in Russia and ultimately discharges into the Sea of Okhotsk; the Lancang River, which is named the Mekong River in other countries, flows to the South China Sea through Burma, Laos, Thailand, Cambodia and Vietnam; the Huaihe River flows to the Hongze Lake and then reaches the sea through the Yangtze River, or discharges into the sea directly through the diversion channel constructed in 2003. Other rivers exit into the sea directly.

Long term data series of runoff and sediment loads from representative gauging stations on the 10 major rivers are selected and summarised. These data are explored in order to analyze the changes of runoff and sediment fluxes discharged into the Pacific Ocean from Chinese rivers. The data for all rivers, except the Lancang River, were obtained from the annually published China Gazette of River Sedimentation (MWR, 2001-2004; 2005-2008). The most downstream 17 gauging stations were selected, including: Jiamusi Station on the Songhua River, Tieling and Xinmin Stations on the Liaohe River, Haihezha Station on the Haihe River, Lijin Station on the Yellow River, Bengbo and Linyi Stations on the Huaihe River, Datong

Station on the Yangtze River, Lanxi, Zhuqi and Huashan Stations on the Qiantang River, Zhuqi and Yongtai Stations on the Minjiang River, Boluo, Shijiao and Gaoyao Stations on the Pearl River, and Yunjinghong Station on the Lancang River (Figure 1).



Gauging stations on the studied rivers:

1. Jiamusi station on the Songhua River
2. Tieling & Xinmin stations on the Liaohe River
3. Haihezhai station on the Haihe River
4. Lijin station on the Yellow River
5. Bengbu & Linyi stations on the Huaihe River
6. Datong station on the Yangtze River
7. Lanxi, Zhuji & Huashan stations on the Qiantang River
8. Zhuqi & Yongtai stations on the Minjiang River
9. Boluo, Shijiao & Gaoyao stations on the Pearl River
10. Yunjinghong station on the Lancang River

Figure 1 The studied rivers and gauging stations

2. DATA COLLECTION AND ANALYZES

Of the 10 rivers selected for analysis, the data series for the 16 gauging stations on the 9 rivers obtained from the China Gazette of River Sedimentation commenced between 1950 and 1977, with most starting around 1955 (Table 1). The runoff and sediment data for the Yunjinghong Station on the Lancang River were obtained from You (1999). The period of measurement is from 1965 to 1987. From the Table 1, it can be seen that the upstream areas of these gauge stations account for the majority of the total catchment areas. For convenience in synthesising the data from the 10 rivers, the duration of the data series used for the analysis was standardised as 1955 to 2007. The missing data were interpolated by different methods according to specific conditions. During the data preparation, all inconsistencies were carefully treated and detected errors were corrected.

The total runoff and sediment fluxes of each river were estimated by multiplying the values of the representative stations by the ratios of the total and the upstream drainage areas (Table 2).

The missing data from 1955 to 1964 of the Xinmin Station on the Liaohe River were infilled by interpolation. This interpolation considered correlation coefficients of the annual runoff and sediment loads between the Xinmin and Tieling Stations.

The missing data of Haihezha Station on the Haihe River were replaced by using the long term average values.

The data series of the Lanxi Station on the Qiantang River started from the year of 1977. Therefore, the water and sediment missing data from 1956 to 1976 of the Lanxi Station were substituted by an interpolation which considers the correlation coeffients of the annual runoff and sediment loads between its data and “Zhuji + Huashan” stations. Because there are no data for 1955 from any of the three stations, the annual runoff and sediment loads of “Lanxi + Zhuji + Huashan” stations were substituted by using the long term average values.

Table 1 Representative Gauging Stations and Duration of the Data

River	Guaging Station	Upstream Drainage Area (km^2)	Catchment Area(km^2)	Duration of the Data	Ratio between the Total and the Upstream Drainage Areas
Songhua	Jiamusi	528277	557180	1955-2007	1.05
Liaohe	Tieling Xinmin	127523	228960	1954-2007 1965-2007	1.80
Haihe	Haihezha		263631	1960-2007	
Yellow	Lijin	752032	752443	1952-2007	1.00
Huaihe	Bengbo Linyi	131645	269283	1950-2007 1954-2007	2.05
Yangtze	Datong	1705383	1808500	1950-2007	1.06
Qiantang	Lanxi Zhuji Huashan	22995	42156	1977-2007 1956-2007 1956-2007	1.83
Minjiang	Zhuqi Yongtai	58534	60992	1951-2007 1951-2007	1.04
Pearl	Boluo Shijiao Gaoyao	415223	453690	1954-2007 1954-2007 1957-2007	1.09
Lancang	Yunjinghong	140933	147468	1965-1987	1.05

Table 2 Average Annual Runoff and Sediment Fluxes into the Pacific Ocean from Chinese rivers between 1955 and 2007

River	Station		Ratios between the Total and the Upstream Drainage Areas	Catchment		Runoff as percentage of total (%)	Sediment flux as percentage total (%)
	Av. Annual Runoff ($10^9 m^3$)	Av. Annual Sediment ($10^6 t$)		Annual Runoff (10^9 m^3)	Annual Sediment Flux (10^6 t)		
Songhua	63.9	12.50	1.05	67.4	13.19	4.3	0.9
Liaohe	3.1	19.84	1.80	5.6	35.63	0.4	2.6
Haihe	0.9	0.08		0.9	0.08	0.1	0.0
Yellow	29.9	724.12	1.00	29.9	724.52	1.9	52.1
Huaihe	28.3	10.47	2.05	57.9	21.42	3.7	1.5
Yangtze	885.1	400.86	1.06	938.6	425.09	60.0	30.5
Qiantang	19.9	3.15	1.83	36.5	5.78	2.3	0.4
Minjiang	56.2	6.33	1.04	58.6	6.60	3.7	0.5
Pearl	282.2	73.51	1.09	308.3	80.32	19.7	5.8
Lancang	57.3	75.68	1.05	59.9	79.19	3.8	5.7
Total	1426.8	1326.54		1563.6	1391.80		

Only a few years of data are missing for the Pearl River. The annual sediment loads were not measured in the Shijiao Station during 1970 to 1973, whereas the annual runoff was measured. Thus, the missing values of the annual sediment loads were calculated by multiplying the long term average sediment concentration by the annual runoff. The data of Gaoyao Station in 1955 and 1956 were interpolated by using data of “Boluo + Shijiao” stations following the same method applied for other rivers.

Many years of data are lacked in the data series of Yunjinghong Station on the Lancang River. Fortunately, the annual runoff data during 1955 to 1964 and from 1988 to 2001 can be obtained from You (2005), and the annual average sediment concentration during 1988 to 2001 can be acquired from Fu (2006). Therefore, the annual sediment loads during 1988 to 2001 can be calculated by multiplying the annual runoff by the annual sediment concentrations. The sediment data from 1955 to 1964 are approximately determined by multiplying the annual runoff by the long term average sediment concentration, 1.23 kg/m^3. Considering there are no reference data available from 2002 to 2007, the water and sediment data in this period were substituted by the long term average values.

3. VARIATION OF RUNOFF AND SEDIMENT FLUXES

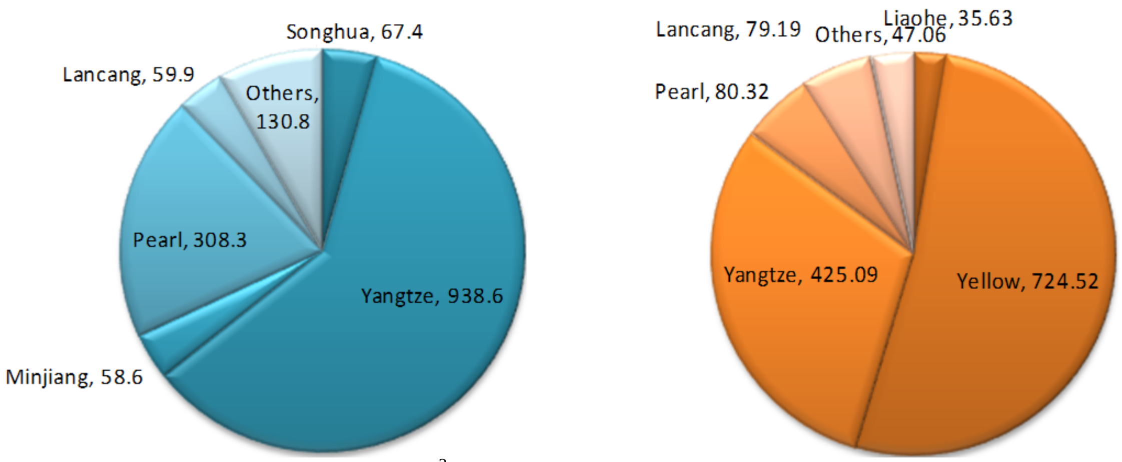
3.1 Long Term Average Runoff and Sediment Fluxes

The prepared data series of annual runoff and sediment loads for the 10 major rivers flowing into the Pacific Ocean during 1955 to 2007 were analyzed. The data series of total annual runoff and sediment flux from the Chinese rivers into the Pacific Ocean can be obtained by combining the records for the individual rivers. Table 2 lists the general status showing the spatial distribution of the water and sediment fluxes. It can be seen that:

(1) The average annual runoff and sediment flux from Chinese rivers into the Pacific Ocean are approximately 1,560 billion m^3 and 1,390 million tonnes per year, respectively;

(2) The top 5 rivers related to the largest quantities of runoff flow into the Pacific Ocean are the Yangtze, Pearl, Songhua, Lancang and Minjiang Rivers; the flow of these 5 rivers account for 92% of the total. The average annual flow of the Yangtze and the Pearl Rivers are 939 and 308 billion m^3 per year, respectively, which accounts for 80% of the total (Figure 2);

(3) The top 5 rivers related to the largest quantities of sediment loads into the Pacific Ocean are the Yellow, Yangtze, Pearl, Lancang and Liaohe Rivers; the sediment fluxes of these 5 rivers accounts for 97% of the total. The average annual sediment loads of the Yellow and the Yangtze Rivers are 725 and 425 million tonnes per year, respectively which accounts for 83% of the total (Figure 2).



(a) Average annual runoff (Billion m^3) (b) Average annual sediment load (Million tonnes)

Figure 2 Chinese Rivers Contribution to the Runoff and Sediment Fluxes into the Pacific Ocean

3.2 Changes of runoff and sediment fluxes

Figure 3 shows the changes of runoff and sediment load flowing into the Pacific Ocean from Chinese rivers in different decades, 1950s (1955-1959), 1960s (1960-1969), ……, 1990s (1990-1999) and 2000s (2000-2007). The average annual runoff fluxes present small variations, ranging from 1,470 to 1,660 billion m^3 per year. The highest values occur in 1990s and the lowest in 2000s. However, the average annual sediment loads provide evidence of a declining trend. The decade average value in 1950s of 2,270 million tonnes per year decreased for the next decades respectively for 1,920, 1,590, 1,360, 970 and 520 million tonnes per year. The average annual sediment flux into the Pacific Ocean in the 2000s is less than 1/4 of that recorded for the 1950s.

Figure 4 shows the annual fluctuation of the annual runoff and sediment fluxes entering into the Pacific Ocean from Chinese rivers. In general, the runoff fluxes over the observed 53-year are quite stable and present no tendency to change over this period. The maximum annual runoff flux is 2,060 billion m^3, which occurred in 1998, is 32% higher than the long term average value. In 1998, China suffered massive flooding in three areas during the summer: Along the Yangtze River in south central China; Nenjiang and Songhua river basins in north east of China; and the West River in the Pearl River basin and Minjing River in southern China. It is reported that the floods affected 186 million people and killed 4,150, destroyed 6.85 million houses, flooded 25 million hectares of farmland, and caused damage estimated to total over 255 billion Chinese Yuan (equivalent to US $30 billion at that time).(MWR, 1998). The minimum annual runoff occurred in 1972 and the value of 1,260 billion m^3, is 19% lower than the long term average value. In 1972, people worldwide witnessed long-lasting drought all over the world. Precipitation was reduced over most part of China, and large areas of northern China experienced the most severe drought in a 30-year period. The area of drought-stricken farmland was over 3070 billion hectares in which the area of farm crops affected by drought was over 1360 billion hectares.

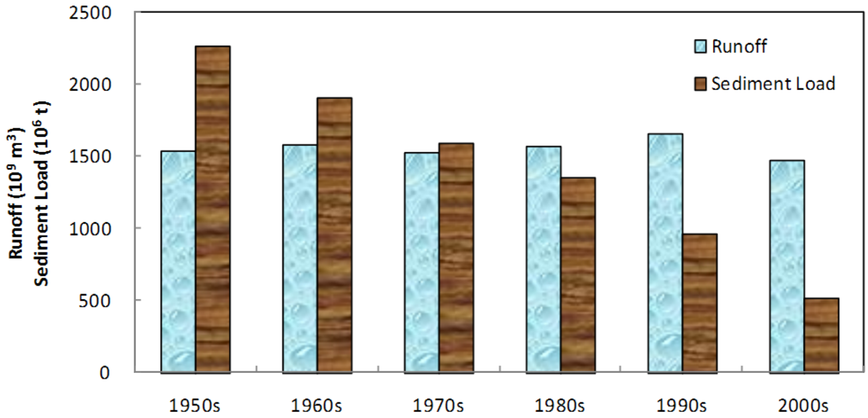


Figure 3 Changes of Runoff and Sediment Loads Drainaging to the Pacific Ocean from Chinese rivers in defferent Decades

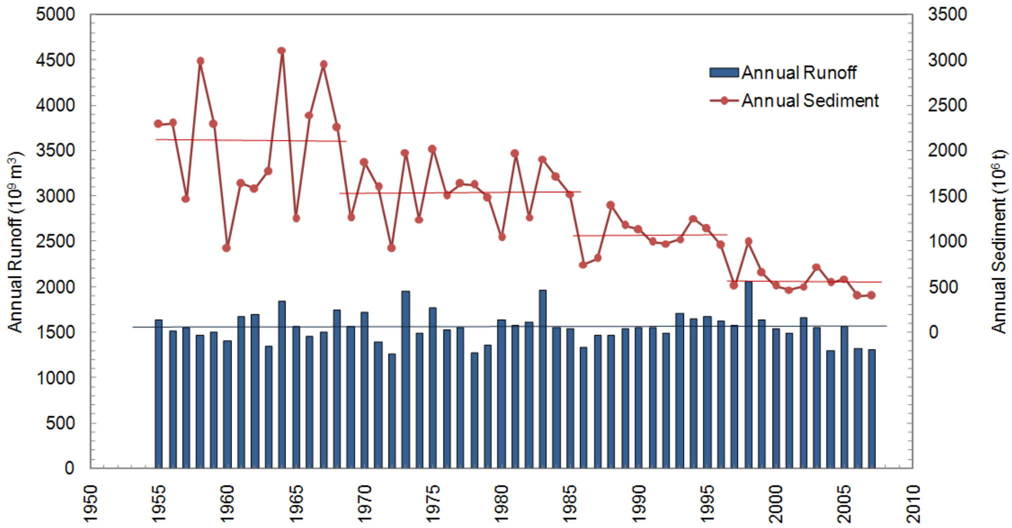


Figure 4 Changes of Annual Runoff and Sediment Fluxes entering into the Pacific Ocean from Chinese Rivers

The annual sediment flux discharging into the Pacific Ocean from Chinese rivers presents a clear downward trend. The maximum value occurred in 1964 and is 3,110 million tonnes**;** the minimum value happened in 2006 and is 400 million tonnes (Figure 4). In order to reveal the change tendency of sediment flux, a double mass curve of annual runoff and sediment fluxes is presented in Figure 5. It can be seen from Figure 5 that there are 3 distinct turning points taking place in 1969, 1986 and 1997, which means that in these 3 years were initiated tendencies of decrease for the annual sediment flux into the Pacific Ocean from Chinese rivers.

As shown in Table 3 and Figure 4, the annual sediment fluxes decreased clearly in 4 steps, during the periods of 1955-1968, 1969-1985, 1986-1996 and 1997-2007. The annual sediment fluxes decreased from 2,087 million tonnes in 1955 – 1968 to 575 million tonnes in 1997 – 2007.

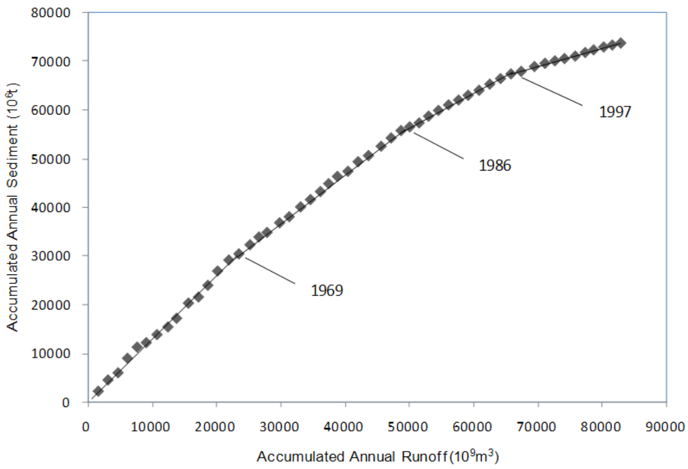


Figure 5 Double Mass Curve of Annual Runoff and Sediment Flux

Table 3 Stepwise Decrease of Annual Sediment Fluxes into the Pacific Ocean from Chinese rivers

Period	1955-1968	1969-1985	1986-1996	1997-2007
Average Annual Sediment Fluxes (M tonnes)	2087	1557	1063	575

4. CONCLUSIONS AND DISCUSSIONS

Seventeen representative gauging stations on 10 major rivers in the Mainland of China flowing into the Pacific Ocean were selected. The long term data on annual runoff and sediment load for each station were prepared and analyzed. The long term data series of annual runoff and sediment flux into the Pacific Ocean from Chinese rivers over an observed 53-year period were summarized. The following conclusions can be drawn.

(1) The average annual runoff into the Pacific Ocean from Chinese rivers is about 1,560 billion m^3, in which the annual runoff from the Yangtze and Pearl Rivers account for 80% of the total. The annual runoff into the Pacific Ocean has shown no tendency to change over the last decades. The maximum annual runoff recorded was 2,057 billion m^3 (1998) and the minimum recorded was 1,260 billion m^3 (1972).

(2) The average annual sediment flux into the Pacific Ocean from Chinese rivers was 1,392 million tonnes, in which the annual sediment fluxes from the Yellow and Yangtze Rivers account for 83% of the total. The maximum annual sediment flux registered in 1964 was 3,110 million tonnes and the minimum value registered in 2006 was 401 million tonnes. The sediment flux decreases sharply over the last decades, with evidence of 4 stepwise changes from 2087 million tonnes in 1955 – 1968 to 575 million tonnes in 1997 – 2007.

(3) The annual runoff into the Pacific Ocean has presented no change tendency, this is because the annual runoff fluxes of the Yangtze, Pearl and other rivers in south China, which contribute the majority of the total runoff to the seas, have no changing trend (Liu et al. 2008). However, influenced by human activities (such as dam construction and reservoir regulation, water supply and irrigation, and water and soil conservation) and global climate change, the runoff of the rivers north of the Huaihe River provide clear evidence of a decline (Liu et al. 2007). The annual runoff of the Yellow River entering the sea decreased sharply from nearly 50 billion m^3 in 1950s and 1960s to only a little over 10 billion m^3 over the two recent decades (Liu et al. 2008).

(4) The annual sediment fluxes of all 9 rivers, except the Songhua River, have presented downward tendencies. The annual sediment loads of the Yellow and Yangtze Rivers, which contribute the majority of the total flux, initiated a declining trend from the 1970s and 1990s, respectively. Considering only the Yellow River, the annual sediment fluxes entering the sea decreased from about 1,400 million tonnes in 1950s to 170 million tonnes in 2000s. The decreasing sediment flux into the Pacific Ocean is due to the integrative effects of soil and water conservation measures, water and sediment regulation by reservoirs, sediment abstraction by irrigation, and climate change. Reservoir construction and changes of reservoir operation modes may cause accentuated changes in the sediment flux.

This paper illustrates a framework concerning the runoff and sediment fluxes into the Pacific Ocean from Chinese rivers during 1955 to 2007. However, there is a huge interest in developing a methodology to estimate future values, for example, for the next decade. In this sense and as future scientific investigation, the related dataset should be explored by using Data Mining and Geographic Information Systems in order to build predictive models for future values of runoff and sediment fluxes.

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