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# Spatio-temporal trends and causes of variations in runoff and sediment load of the Jinsha River in China

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**Abstract:** The Jinsha River Basin is an important basin for hydropower in China and it is also the main runoff and sediment source area for the Yangtze River, which greatly influence the runoff and sediment in the Three Gorges Reservoir. This study aims to characterize the spatial distribution, inter-annual variation of runoff and sediment load in the Jinsha River Basin, and to analyze the contribution of rainfall and human activities to the runoff and sediment load changes. The monitoring data on runoff, sediment load and precipitation were collected from 11 hydrological stations in the Jinsha River Basin from 1966 to 2016. The data observed at the outlet of the basin showed that 71.4% of the runoff is from the upper reaches of the Jinsha River Basin and the Yalong River, while 63.3% of the sediment is from the lower reaches (excluding the Yalong River). There is no significant increase in runoff on temporal scale in the Jinsha River Basin, while it has an abrupt change in runoff in both upstream and midstream in 1985, and an abrupt change in downstream in 1980 and 2013. The sediment load demonstrated a significant increasing trend in the upstream, no significant reducing trend in the midstream, but significant reducing trend in the downstream. The sediment load in upstream showed abrupt change in 1987, in midstream in 1978 and 2014, in downstream in 2012. Rainfall dominated runoff variation, contributing more than 59.0% of the total variation, while human activity, including reservoirs construction, the implementation of soil and water conservation projects, is the major factor to sediment load variation, contributing more than 87.0% of the total variation.

**Keywords:** Jinsha River Basin; Runoff; Sediment load; Rainfall; Cascade reservoir; Three Gorges Reservoir

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## Introduction

Runoff and sedimentary processes play an important role in maintaining the structure and function of the river. Runoff reflects the basic power shaping the river bed and sediment is the material basis for changing the shape of the river bed (Benn and Erskine 1994). The variation of runoff and sediment will change the scouring and silting characteristics, directly affect the flood control, irrigation and navigation of reservoirs and rivers. Both natural (including rainfall change, temperature change) and human factors (including reservoir construction, soil and water conservation, river sand mining) have a profound impact on runoff and sediment conditions (Sharda and Ojasvi 2016). Studies have shown that the spatial and temporal (interseasonal and interannual) distributions of runoff and sediment affected by human activity and climate change in the Nile River, the Colorado River, the Yangtze River and the Yellow River have changed significantly (Walling and Fang 2003; McCarney-Castle et al. 2010; Fanos 1995; Kong et al. 2015; Carriquiry and Sanchez 1999; Fu et al. 2017; Mikhailov and Mikhailova 2017). Research on runoff and sediment variation has a long history. Commonly used research methods include Mann-Kendall analysis, mean difference T test, pettitt test, double mass curve method, morlet wavelet analysis (Chalov et al. 2017; Liu and Wang 2015). The scope of research also covers from large rivers and lakes to small watersheds around the world. Chalov et al. (2018) analyzed the sediment transport in major rivers in Asia including Selenga River and Yangtze River, and considered that reservoir construction was the most important factor in the sediment load decreasing in these basins. Burn and Hag Elnur (2002) found the characteristics of the 48-year sequence hydrological parameters in 248 catchments in Canada were due to variation in natural climatic conditions. Wang et al. (2008) reconstructed the sediment flux of the Yangtze River from the 1860s to 2005. It was believed that the Yangtze River sediment load after 1950 was much more disturbed by human activities than before. In recent years, with the rapid development of water conservancy and hydropower, the impact of reservoir construction on runoff and sediment has gradually become a hot research topic. The construction and operation of large reservoirs is one of the main human activities which have a significant impact on the runoff and sediment conditions of rivers (Charles et al. 2003; Sharda and Ojasvi 2016; Zhao et al. 2014; He et al. 2016). Present studies show that the sediment load of many large rivers is significantly reduced after the construction of reservoirs and dams (Xu and Yan 2010; Shi et al. 2017), such as the Three Gorges Dam on the Yangtze River (Guo et al. 2012), the Aswan High Dam on the Nile (Strzepek et al. 2008) and the Hoover Dam on the Colorado River (Kwak et al. 2014). The research shows approximately 26.0% of the sediment has been remaining in the reservoirs (Zhao et al. 2014). With the global climate change and rapid development of hydropower exploitation in various regions, the variation of runoff and sediment have become important issues that cannot be ignored (Zhang et al. 2017). The identification and assessment of the impacts of climate change and human activities on runoff and sediment have become important topics and challenges in current research fields (McCarney-Castle et al. 2010).

Jinsha River is the largest river in the upper reaches of the Yangtze River and it plays an important role in the aquatic and sediment security of the Three Gorges Reservoir. The drainage area, annual runoff and sediment contribution of the Jinsha River Basin accounts for 45.6%, 33.0% and 60.0% of the total for the upper reaches of the Yangtze River (Xu 2009). For a long time, the middle and upper reaches of the Jinsha River basin had a small population and were weakly interfered by human activities. However, with the development of various aspects of the basin in recent years, the degree of interference has gradually increased in this area, particularly, the lower reaches has more population, the interferences of human activities are dense, and the vegetation was degraded in this area, although the soil and water conservation projects had started in the downstream areas since 1989 (Chen et al. 2008; Wang 2012). In recent years, with the development of hydropower resources in the Jinsha River Basin, a series of cascade reservoirs in the midstream and downstream have been successively impounded, and the conditions for runoff and sediment have been greatly changed. Some previous studies have been carried out on the characteristics of runoff and sediment in the Jinsha River Basin. Xu (2009) discussed the relationship between sediment loss and reservoir construction with respect to the early stages of the construction of the cascade reservoir in the Jinsha River Basin. Feng et al. (2008) assessed the amount of sediment reduction from the Yalong River into the main stream of the Jinsha River after the operation of Ertan Reservoir, by regression analysis. Duan et al. (2015) concluded that the sediment-blocking effect of the cascade reservoir in Jinsha River would significantly reduce the sediment transport into the Three Gorges Reservoir by the Brune sand retention rate method. Lu et al. (2016) analysed the climate and runoff variation in the Jinsha River Basin from 1951 to 2010 by the Mann-Kendall test and concluded climate change cause an increase in runoff.

In general, present researches concentrate on the sediment-blocking effects of as-built reservoirs. At present, there is still an inadequate understanding of the new characteristics and trends of runoff and sediment in the Jinsha River Basin. In this study, we base on the monitoring data of the Jinsha River Basin from 1966 to 2016, and aim to 1) analyse the spatial distribution characteristics of runoff and sediment, 2) explore the temporal trend of annual runoff and sediment, detect their abrupt times, and 3) determine the contribution of rainfall and human activities to the runoff and sediment variation in Jinsha River Basin.

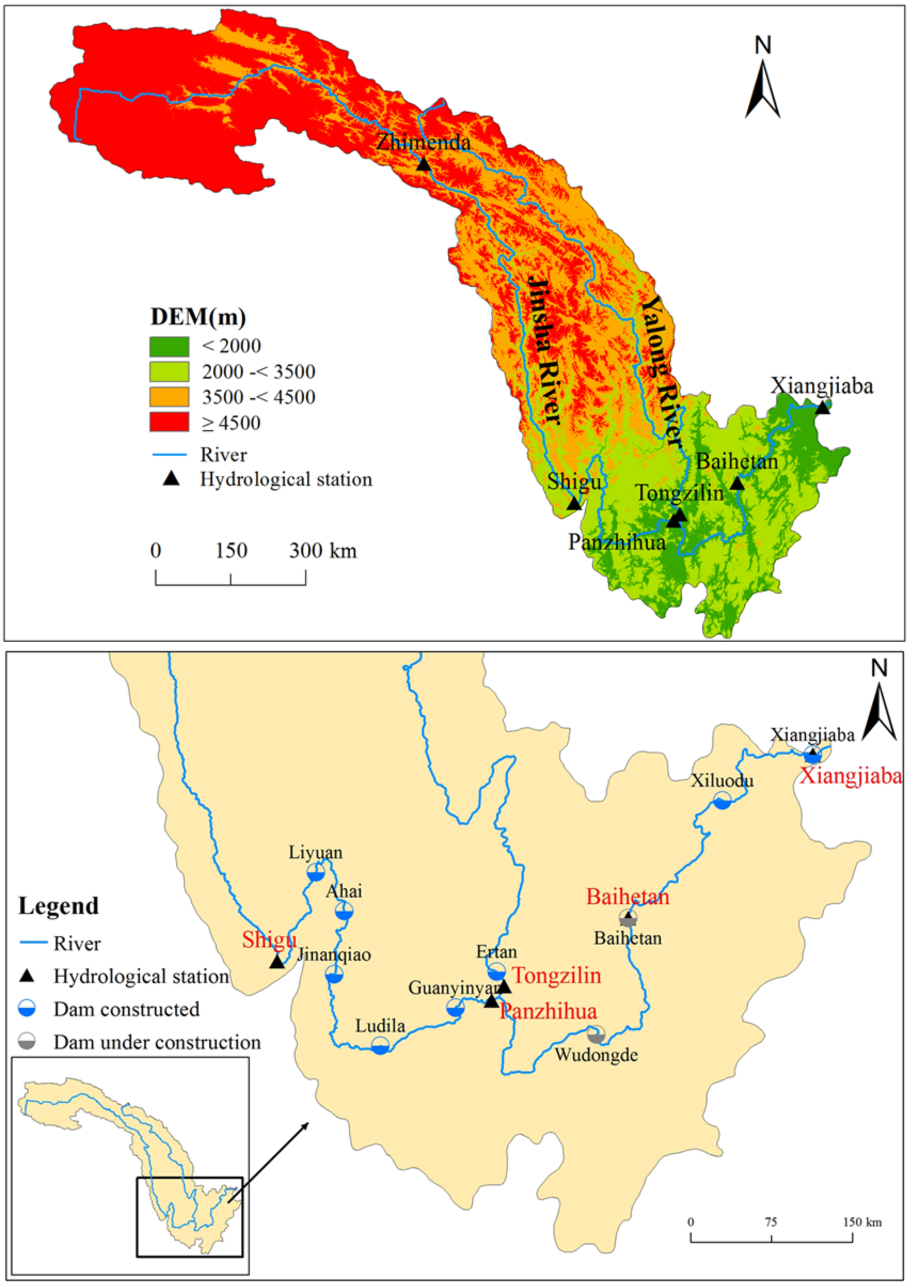


**Figure 1** Location of the Jinsha River Basin.

## 1 Materials and Methods

### 1.1 Study area

The Jinsha River Basin is located in the upper reaches of the Yangtze River (90-105°E, 24-36°N) (Figure 1) with an area of approximately 470,000 km² and accounting for 26.3% of the Yangtze River Basin. The main river is divided into upper, middle and lower reaches with hydrometric stations at Shigu, Panzhihua and Xijiaba, respectively. The upstream section is 965 km long, the midstream section is 564 km long and the downstream river length is approximately 768 km. The area is influenced by tropical monsoon, subtropical monsoon, plateau monsoon and complex terrain. The basin's climate type is complex and diverse, including a sub-cold, semi-arid plateau climate and a subtropical, humid monsoon climate. The average annual temperature of the basin is 3.0°C. Temperature generally increases from the northwest to the southeast. The average annual temperature of the upper area is below 0.0°C, while that of the middle and lower reaches is above 19.0°C. The average annual precipitation is 753 mm and this also increases from the northwest to the southeast, with downstream precipitation being 3.83 times that of the source area (Lu et al. 2016). The flood season of Jinsha River is from May to October. The runoff and sediment in the flood season account for 68.2 to 80.2% and 85.5 to 98.2% of the totals, respectively. The total rainfall of the Jinsha River is 3300 m and the hydraulic resources are more than 100 million kW, accounting for more than 40.0% of the Yangtze River's total hydraulic resources (an important hydropower base in China).

The upper reaches of the Jinsha River are sparsely populated and less interfered by human activities. The middle reaches of the Shigu-Panzhihua section also less affected by human activities before, but in recent years the effects are gradually enhanced, such as the cascade reservoirs Liyuan and Guanyinyan that have been constructed and operated since 2010, as well as mining activities in areas such as Panzhihua. The human activities in the downstream reaches are relatively strong. In recent years, a series of cascade reservoirs were constructed and operated in the lower reaches of the Jinsha River, which include four giant cascade reservoirs: Wudongde (under construction), Baihetan (under construction), Xiluodu and Xiangjiaba. These reservoirss have a total installed capacity of approximately 40 million kW, an average annual generating capacity of more than 185 billion kW and a total storage capacity of more than 410 billion $m^3$.

### 1.2 Data sources

In order to reflect the changing characteristics of runoff and sediment in the Jinsha River Basin, The main hydrological stations includes the upstream control station Shigu, the midstream control station Panzhihua, and the downstream control station Pingshan (Xiangjiaba) were selected. In addition the representative main stream hydrological stations were selected, including Sanduizi, Wudongde, Huatan(Baihetan), Xiluodu. The representative main tributary stations were also selected, including Tongzilin (Yalong River), Huangguayuan (Longchuan River), Ningnan (Heishui River), Meigu (Meigu River) (Table 1). Monitoring data (including annual runoff and annual sediment load) from 1966 and 2016 were gathered from these stations. All data were pre-processed by quality control and eliminated large differences data, meanwhile complete missing data by interpolation method. The hydrological monitoring data and hydrological station information of the main stream and tributaries of the Jinsha River Basin come from the Hydrologic Bureau of the Yangtze River Water Conservancy Commission, the Three Gorges Corporation of China, the Sichuan Hydrographic Bureau, the Yunnan Hydrological Bureau, the Chengdu Institute of Survey and Design, Central South Survey and Design Research Institute. The basic data for the cascade reservoirs was obtained from China Three Gorges Corporation. The precipitation data (including monthly precipitation and annual precipitation) from 1966 to 2016 was obtained from the National Meteorological Information

**Table 1** Basic information of hydrological stations in the Jinsha River Basin, China

| Hydrometric station | River basin | Control area ($km^2$) | Percentage to Xiangjiaba control area (%) | Period |
|---|---|---|---|---|
| Shigu (SG) | Jinsha (upstream) | 214184 | 46.7 | 1957-2016 |
| Panzhihua (PZH) | Jinsha (middle reaches) | 259177 | 56.5 | 1965-2016 |
| Sanduizhi (SDZ) | Jinsha (downstream) | 388571 | 84.7 | 2006-2016 |
| Wudongde (WDD) | Jinsha (downstream) | 406142 | 88.5 | 2003-2016 |
| Baihetan (BHT) | Jinsha (downstream) | 430308 | 93.8 | 1957-2016 |
| Xiluodu (XLD) | Jinsha (downstream) | 454400 | 99.0 | 1999-2016 |
| Xiangjiaba (XJB) | Jinsha (downstream) | 458800 | 100.0 | 1955-2016 |
| Tongzilin (TZL) | Yalong | 128363 | 28.0 | 1962-2016 |
| Huangguayuan (HGY) | Longchuan | 5560 | 1.2 | 1953-2016 |
| Ningnan (NN) | Heishui | 3704 | 0.8 | 1953-2016 |
| Meigu (MG) | Meigu | 1607 | 0.4 | 2006-2016 |

Center of China Meteorological Administration (http://data.cma.cn), and the data was measured and recorded by the main weather stations in the basin. There were little missing data of hydrological and climatic observations in research period, and the missing data were completed by the interpolation method. The digital elevation model (30m×30m) was from Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn).

During the process of data acquisition, the determination of runoff and sediment load was carried out in accordance with the national standard issued by China Ministry of Water Conservancy and Power (1962 and 1975); the water level involved in the study is taken as being a frozen base surface and the sediment load comprises suspended sediment. The procedures and methods of hydrological surveys, sampling and laboratory analysis are basically the same in China as those used internationally. Strict inspection and error analysis are performed during data processing to ensure accuracy (Xu and Yan 2010).

## 1.3 Methods

### *1.3.1 Mann-Kendall (M-K) rank correlation test*

The M-K rank correlation test is a non-parametric statistical test method. The advantage of the test method is that it does not require a sample to follow a certain distribution and is not disturbed by a few anomalous values; it is most suited to the trend research of long-term series of hydrological processes (Yue et al. 2002). The main series of runoff and sediment in the Jinsha River Basin is relatively complete. Thus, the M-K rank correlation test was used to analyse the trends in runoff and sediment variation.

(1) M-K trend test

The basic principle of the M-K trend test method assumes a time series X, where n is an independent, random variable and the same distribution sample ($x_1$, $x_2$, ..., $x_n$) (Zhang et al. 2007), constructs a sequence of order:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn\left(x_j-x_k\right) \tag{1}$$

where: $sgn\left(x_j-x_k\right)=\begin{cases}1 & x_j>x_k\\ 0 & x_j=x_k\\ -1 & x_j<x_k\end{cases}$

$S$ is approximately obeying a normal distribution and its average value $E\left(S\right)=0$.

Variance:

$$Var\left(S\right)=n\left(n-1\right)\left(2n+5\right)/18 \tag{2}$$

When $n$>10, the standard normal distribution test statistic $Z$ is:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{Var(S)}} & S>0\\ 0 & S=0\\ \dfrac{S+1}{\sqrt{Var(S)}} & S<0\end{cases} \tag{3}$$

For the statistical variable $Z$, it trends upwards when it is more than 0 and downwards when it is less than 0. When the absolute value of $Z$ is equal to or more than 1.28, 1.96 and 2.32, this represents test confidence levels of 90%, 95% and 99%, respectively.

(2) M-K abrupt test

The test method in the M-K abrupt test differs from the M-K trend test. In the abrupt test process, an order column $S_k$ needs to be constructed. $S_k$ is the cumulative number of sample $x_i$ that is larger than $x_j$ (1≤j≤i):

$$S_k=\sum_{i=1}^{k} r_i \qquad \left(k=2,3,4,\ldots,n\right) \tag{4}$$

where: $r_i=\begin{cases}1 & x_i>x_j\\ 0 & x_i\le x_j\end{cases} \quad 1\le j\le i$

Its average value and variance:

$$E\left(S_k\right)=n\left(n-1\right)/4 \tag{5}$$

$$Var\left(S_k\right)=n\left(n-1\right)\left(2n+5\right)/72 \tag{6}$$

Finally, define the statistical variables:

$$UF_k=\left[S_k-E\left(S_k\right)\right]/\left[Var\left(S_K\right)\right]^{1/2} \quad \left(k=1,2,3,4,\ldots,n\right) \tag{7}$$

where $UF_1=0$ and $UF_i$ is a standard normal distribution. There is an upward trend when the $UF_k$ value is more than 0, while there is a downward trend when it is less than 0. If a significant level $\alpha$ is given, according to the normal distribution table, we get the critical value $t_0$ and, if $|UF_k| > t_0$, this indicates that there is an obvious change trend in the sequence.

Sequence X is arranged in reverse order to give a new sequence X' ($x_n$, $x_{n-1}$, ... $x_1$), then calculated according to the upper formula. If the result is multiplied by -1, then we get the reverse sequence's statistic $UB_k$, where $UB_1 = 0$. When the two curves $UF_k$, and $UB_k$ intersect and the intersection point is between the confidence lines, then the intersection point is the abrupt point.

(3) Yamamoto abrupt point identification

The abrupt points obtained by the above-mentioned M-K abrupt test may include true abrupt points and false abrupt points. Therefore, the Yamamoto abrupt test is used to identify the abrupt points. The Yamamoto method judges the true abrupt point by checking whether the difference between the two-orders' mean values is significant (Li and Chang 2012; Chai et al. 2017). To define a signal-to-noise ratio (SNR) for a sequence, the equation is as follows:

$$SNR = \left|\bar{x}_1 - \bar{x}_2\right| / (S_1 + S_2) \qquad (8)$$

Where $\bar{x}_1$, $\bar{x}_2$ and $S_1$, $S_2$ are the mean and variance of sub-sequences before and after the checkpoint, respectively. When the sub-sequence capacity is $n_1 = n_2 = n$, based on the t-test formula, the t-test value $t > SNR\sqrt{n}$ can be derived. When $n = 10$, $SNR = 1$, then available $t > 3.162$. Under this condition, the threshold of significant level $\alpha = 0.01$ is $t_{0.01} = 2.878$. Thus, $t > t_\alpha$ can be drawn to exceed the given significant level. Where there is a significant difference between the two sub-sequences, it can be determined that an abrupt point has occurred at this point. Thus, under the condition when $SNR > 1$ exceeds the given confidence level, this indicates that an abrupt has occurred and when $SNR > 2$, then a strong abrupt has occurred. $SNR < 1$ represents a false abrupt. In the actual calculation process, the SNR threshold can be changed according to different samples and confidence levels (Fu and Wang 1992; Li and Chang 2012). The sub-sequences' size n can usually be set as needed, in order to show the results concisely; $n = 10$ was chosen in this study as it is commonly used in long-term, sequence analysis.

### *1.3.2 Double mass curve method*

The double mass curve is a common method for testing the consistency and variation of the relationship between two variables. The main process is as follows: with 2 variables (say, *X* (rainfall) and *Y* (runoff or sediment)), there are samples $X_i$ and $Y_i$ (where $i$ =1, 2, 3... $n$) in the study period. Calculate cumulative values in chronological order, respectively, thereby obtaining new sequences $X'$ and $Y'$. Then draw a scatter plot for the cumulative sequences $X'$ and $Y'$ and fit the regression equation. This verifies the consistency of variable *X* and variable *Y* and is used to analyse its trend and intensity.

### *1.3.3 Slope change ratio of cumulative quantity method*

We used the slope change ratio of cumulative quantity method to analyse the contribution of rainfall and human activities to the runoff and sediment variation in the Jinsha River Basin. This method was proposed by Wang et al. (2012) after research in the Huangfu River Basin (a tributary of the Yellow River). The principle was to estimate the influence degree of the factor on the variable, according to the ratio of the cumulative slope change rate of the influence factor to the cumulative slope change rate of the variable. The method is as follows:

(1) Judge the turning point based on the cumulative anomaly

The method judged the turning point according to the cumulative anomaly method which avoids the limitation of the double mass curve method when judging the turning point. The turning point is the point at which the trend changes. For sequence x, its average number:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (9)$$

Cumulative anomaly:

$$\hat{x}_t = \sum_{i=1}^{t}\left(x_i - \bar{x}\right) \quad t = 1,2,3,\ldots,n \qquad (10)$$

The determination of the turning point is based on the discrete magnitude of the data to its mean. If the cumulative anomaly increases, it indicates that the degree of dispersion is more than the average value, and vice versa. When the cumulative anomaly curve shows a transition between an increase and a decrease, the trend transition point is the turning point (Ran et al. 2010).

(2) Determine the contribution rate

In the process of determining the contribution rate of precipitation and human activities to runoff variation, the slopes of the cumulative runoff-year linear relationship for the two periods before and after the turning point are assumed to be $a_{r1}$ and $a_{r2}$, respectively. Then the cumulative runoff slope change rate is calculated as:

$$K_r = 100 \times (a_{r2} - a_{r1}) / a_{r1} \quad (11)$$

Meanwhile, it is assumed that the slopes of the cumulative precipitation-year linear relationship in the two periods before and after the turning point are $a_{p1}$ and $a_{p2}$.Then the cumulative precipitation slope change rate is calculated as:

$$K_p = 100 \times (a_{p2} - a_{p1}) / a_{p1} \quad (12)$$

Where $K_r$, $K_p$ is a positive number indicating an increase in slope, and a negative number indicating a decrease in slope.

The contribution rate of precipitation change to runoff variation can be expressed as:

$$(C_p,\%)\ C_p = 100 \times K_p / K_r \quad (13)$$

The impact of other climate factors such as temperature changes on runoff is very limited compared to precipitation and human activities. Therefore, the contribution rate of human activities can then be expressed as:

$$(C_H,\%)\ C_H = 100 - C_p \quad (14)$$

The calculation method of the contribution rate of rainfall and human activities to sediment load variation is the same as above, and the cumulative runoff-year slope in formula (11) is replaced by the cumulative sediment-year slope, and repeats the above calculations to obtain the contribution rate of precipitation and human activities to sediment load variation.

## 2 Results

### 2.1 Spatial distribution of runoff and sediment load

The spatial distribution of runoff and sediment in the Jinsha River Basin is shown in Table 2. The upper reaches area of the Jinsha River accounts for 46.7% of the basin area: its average annual runoff is $42.4\times10^9$ $m^3$ (accounting for 29.9%), when 1998-2016 period compared to 1966-1997 period, its proportion increased by 0.4%, its average annual sediment load is $25.40\times10^6$ t accounts for 11.4%, which is an area with less runoff and sediment. The proportion of the midstream area, runoff and sediment is only about 10.0%. The runoff of the midstream increased by 2.7%, while the sediment in the middle reaches decreased significantly after 1998. The downstream area (excluding the Yalong River) has a similar proportion in both regional area and runoff. However, the average annual sediment load is $141.1\times10^6$ t, which accounts for 63.3% of Xiangjiaba station (total basin area), being the main source of sediment in the basin. The proportion of sediment from Panzhihua to Baihetan (excluding the Yalong River) accounts for 36.4% of Xiangjiaba station but its area only accounts for 9.3%. In the downstream (excluding the Yalong River) section, the proportion of runoff decreased by 3.5% after 1998, while the proportion of sediment output affected by the construction and operation of cascade reservoirs decreased by 6.0%. The Yalong River (the largest tributary of Jinsha River) basin area accounts for 28.0% of the total basin area, and its average annual

**Table 2** Spatial distribution of runoff and sediment load in the Jinsha River Basin, China

| Region | Area ratio (%) | Runoff ($10^8$ $m^3$) | Runoff ratio (%) | Sediment ($10^4$ t) | Sediment ratio (%) |
|---|---|---|---|---|---|
| Jinsha (upstream) | 46.7 | 424 | 29.9 | 2540 | 11.4 |
| Jinsha (midstream) | 9.8 | 140 | 9.9 | 2230 | 10.0 |
| Yalong River | 28.0 | 590 | 41.6 | 3420 | 15.3 |
| Panzhihua to Baihetan (excluding the Yalong River) | 9.3 | 96 | 6.8 | 8110 | 36.4 |
| Baihetan to Xiangjiaba | 6.2 | 170 | 12.0 | 6000 | 26.9 |

runoff and sediment load accounts for 41.6% and 15.3%, respectively, meaning that the area has more runoff but less sediment. After 1998, the amount of runoff has not changed substantially. However, due to the influence of Ertan Reservoir in the basin, the proportion of sediment in the year after 1998 decreased by 7.7%. In a word, the spatial heterogeneity of runoff and sediment in the Jinsha River Basin is prominent, the runoff mainly comes from the Yalong River and the upper reaches of the Jinsha River, while the sediment mainly comes from the downstream area (excluding the Yalong River).

## 2.2 Interannual variation of runoff and sediment

### *2.2.1 Interannual variation characteristics of runoff and sediment load*

The interannual variation of runoff and sediment at the main hydrometric stations in the Jinsha River is shown in Figure 2. The average annual runoff of the upper hydrometric station at Shigu is $42.4\times10^9$ $m^3$ and its variation coefficient (Cv) is 0.151. The interannual variation is small. The maximum runoff recorded was $54.39\times10^9$ $m^3$ and occurred in 2005, the minimum value was $29.37\times10^9$ $m^3$ in 1994. After 1998, the average annual runoff increased by 4.9%. The average annual sediment is $25.4\times10^6$ t and the variation coefficient is 0.492. The interannual difference is greater than the runoff. The maximum value was recorded in 1998 and the minimum value was $6\times10^6$ t in 1994. After 1998, the average annual sediment load increased by 47.9%. During the study period, the temporal dynamics of runoff and sediment load were basically similar but the sediment load fluctuation was greater. The correlation coefficient between runoff and sediment load has reached 0.891 ($P<0.01$). There is a positive correlation between runoff and sediment with small difference between different periods, indicating that the upper reaches are less affected by human activity.

The average runoff at the middle hydrometric station at Panzhihua is $56.4\times10^9$ $m^3$ and the variation coefficient is 0.158. The interannual variation was also small. The maximum recorded runoff was in 1998 and the minimum runoff ($38.22\times10^9$ $m^3$) appeared in 1994. After 1998, the average annual runoff increased by 15.3%. The average annual sediment is $47.7\times10^6$ t and the variation coefficient reached 0.531. The maximum sediment appeared in 1998 and the minimum value ($2.56\times10^6$ t) in 2015. After 1998, the average annual sediment increased by 5.0%. During the study period, both the runoff and sediment dynamics experienced a rise and then a fall, the sediment reduction being more obvious after 1998. The correlation coefficient of runoff and sediment load in Panzhihua Station of middle reach is 0.772

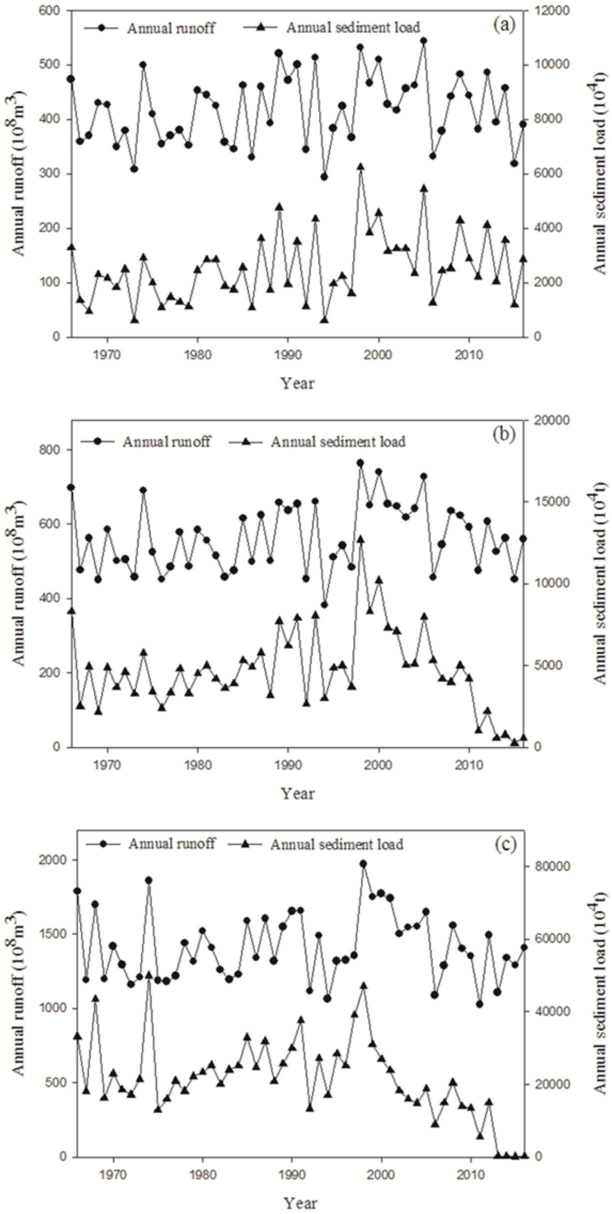


**Figure 2** Runoff and sediment process of three control stations, Shigu (a), Panzhihua (b), Xiangjiaba (c) in 1966 – 2016.

($P$<0.01). The variation of runoff and sediment in the early stage is not apparent, but enhanced in the later period, especially after 2010, and the rate of sediment reduction is much larger than that of runoff, which causes a huge change in the re lationship between runoff and sediment load.

The average annual runoff at the downstream hydrometric station at Xiangjiaba was 142×10$^9$ m$^3$ and the variation coefficient is 0.160. The maximum runoff was 197.1×10$^9$ m$^3$ in 1998 and the minimum was 102.7×10$^9$ m$^3$ in 2011. After 1998, the average annual runoff increased by 4.3%. The average annual sediment is 223×10$^6$ t and the variation coefficient reached 0.513. The maximum sediment appeared in 1974 and the lowest value was 60.4×10$^6$ t in 2015. After 1998, the average annual sediment decreased by 38.6%. In general, the pattern of the temporal dynamics of the runoff and sediment load was similar before 1998, but after 1998 the decreasing trend of the sediment was substantially greater than that of the runoff, the relationship between runoff and sediment load was greatly changed. The correlation coefficient between runoff and sediment load of downstream was only 0.656 ($P$<0.01), and the distribution of runoff and sediment related points was scattered. The difference of runoff and sediment load between different periods was large, indicating that the downstream area was strongly disturbed by human activities.

### *2.2.2 Changing trend of runoff and sediment*

Based on the results of the M-K trend test analysis (Table 3), the runoff M-K statistics at Shigu, Panzhihua, Baihetan, Xiangjiaba and Tongzilin are all greater than 0, but the absolute values did not reach the critical value of 1.96 at a significant level ($\alpha$=0.05) and the increasing trend of annual runoff was not significant. As for sediment load, M-K statistics from the (upstream) Shigu station gave a value of 2.34 and its absolute value exceeded the critical value of 2.32 at a significant level ($\alpha$=0.01), indicating an unusually significant increase in the trend of annual sediment variation at Shigu station. The M-K statistic for Panzhihua station (midstream in the Jinsha River) was -0.18, (which is less than 0) but the absolute value did not reach the critical value of 1.96 at a significant level ($\alpha$=0.05), and the decreasing trend of annual sediment was not significant. The M-K statistic of sediment load at Baihetan station was -2.18 and the absolute value was larger than the critical value at a significant level (α=0.05), suggesting sediment load was significantly reduced. The M-K statistic at downstream hydrometric station Xiangjiaba was -2.84 (less than 0) and the absolute value was above the critical value of 2.32 at a significant level ($\alpha$=0.01), meaning that the decreasing trend of sediment at Xiangjiaba Station was an abnormally significant reduction. In addition, the sediment load of Yalong River decreased significantly. In general, the results of M-K trend analysis showed that the annual runoff in the upper, middle and lower reaches showed an insignificant increase. In terms of sediment load, the upstream showed an abnormally significant increasing trend, the midstream was not significantly reduced, but downstream was significantly reduced.

### *2.2.3 Abrupt analysis of runoff and sediment*

The positive sequence of M-K statistics for runoff is shown in Figure 3. The positive sequence M-K statistic UF curve at Shigu station showed an

**Table 3** M-K trend test of runoff and sediment load at main hydrologic stations in the Jinsha River Basin in China from 1966 to 2016

| Parameter | Hydrometric station (along the process) | Shigu (SG) | Panzhihua (PZH) | Tongzilin (TZL) | Baihetan (BHT) | Xiangjiaba (XJB) |
|---|---|---|---|---|---|---|
| Runoff | MK statistic | 1.300 | 1.170 | 0.504 | 1.007 | 0.585 |
| | Trend | Not significantly increased | Not significantly increased | Not significantly increased | Not significantly increased | Not significantly increased |
| Sediment | MK statistic | 2.339** | -0.179 | -3.103** | -2.177* | -2.843** |
| | Trend | Abnormally significant increase | Not significantly reduced | Abnormally significant reduction | Significantly reduced | Abnormally significant reduction |

**Notes:** * and ** refer to significant and abnormally significant, respectively.

upward trend, in which the UF values were all less than 0 before 1981. This indicated that the runoff in this area was generally decreasing. The UF and UB curve intersections of upstream runoff were in 1985 and located between the 95% confidence lines.

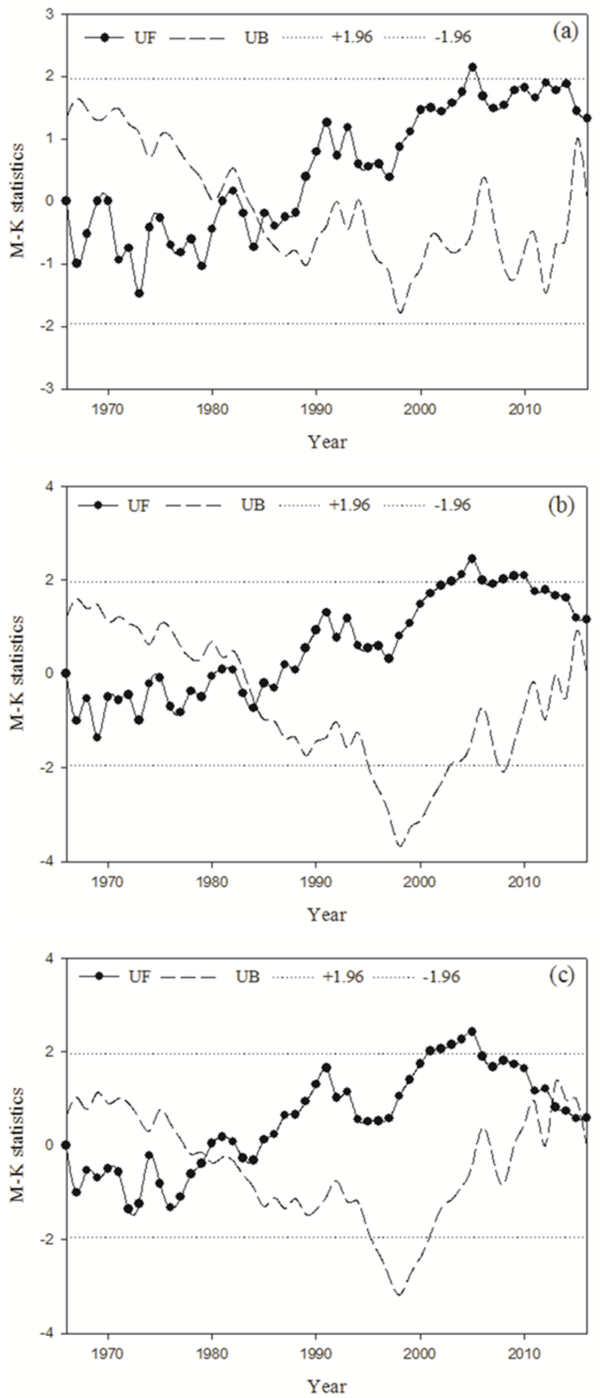


**Figure 3** Runoff M-K abrupt test of three control stations, Shigu (a), Panzhihua (b), Xiangjiaba (c) in 1966 – 2016.

The Yamamoto test showed that when $n=10$, the SNR was 1.608 and the pass 99% confidence level, indicating that 1985 was the abrupt time of the upstream runoff. The UF curve of runoff in the middle reaches at Panzhihua Station increased from 1966 to 2005 and the UF values were all less than 0 before 1981, falling back after 2005. The UF value continued to exceed the critical value of $\alpha$=0.05 between 2003 and 2010. The intersection of the UF and UB curves was also in 1985 and located between the 95% confidence lines. The Yamamoto test showed that the SNR was 2.568, which passed 99% confidence level test, indicating that 1985 was the strong abrupt time of midstream runoff. The positive sequence M-K statistic UF curve at Xiangjiaba station (downstream) also showed an increasing trend from 1966 to 2005. The UF values were all less than 0 before 1980 and decreased after 2005. The M-K statistics for Xiangjiaba station from 2001 to 2005 continued to exceed the critical value with confidence levels ($\alpha$=0. 05) and significantly increased in 2005. The UF and UB curve intersection time of downstream runoff occurred in 1980 and 2013, both being located between the 95% confidence lines. The Yamamoto test showed that the SNR of 1980 and 2013 both exceeded 2 which pass 99% confidence level test, indicating that the 1980 and 2013 were strong abrupt time of downstream runoff. In general, the shapes of the UF runoff curve in the main control stations of Jinsha River are similar and both increased from 1966 to 2005. The UF values were all less than 0 before 1980 and dropped slightly after 2005. The runoff abrupt time of the upstream and midstream sections were both in 1985, and that of downstream in 1980 and 2013.

From Figure 4, it can be seen that the positive sequence of M-K statistic UF curve for sediment load at Shigu station in the upstream part of Jinsha River increased between 1966 and 2016. Before 1982, the M-K statistics were mainly less than 0, with sediment load showing a decreasing trend. The M-K statistics from 2002 to 2016 exceeded the critical value with significant levels ($\alpha$=0.05) and sediment load showed significant increase. The intersection time of the UF and UB curves was in 1987, which located between the 95% confidence lines. The Yamamoto test showed that when $n$=10, the SNR was 2.685 and pass 99% confidence level test, indicating that the 1987 was the strong abrupt

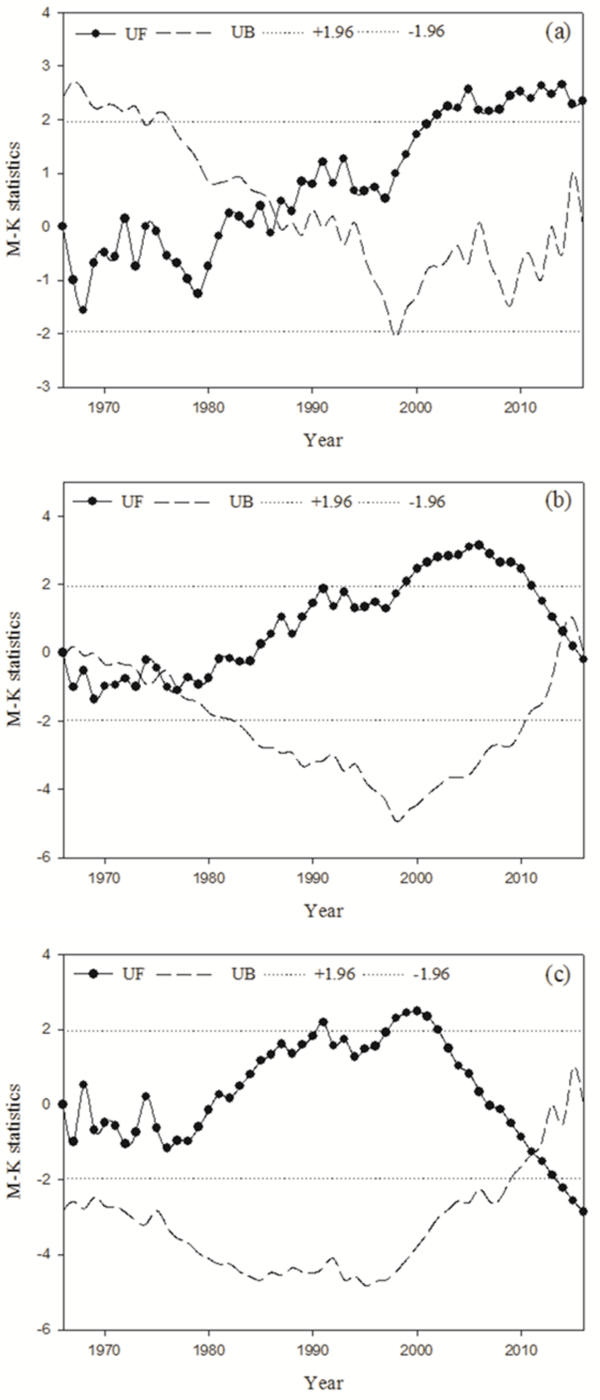


**Figure 4** Sediment load M-K abrupt test of three control stations, Shigu (a), Panzhihua (b), Xiangjiaba (c) in 1966 – 2016.

time of upstream sediment load. The sediment load M-K statistic sequence UF curve at Panzhihua station in the midstream increased between 1966 and 2006 and decreased after 2006; the M-K statistics were mainly less than 0 before 1985. During the period 2000 to 2010, its M-K statistics continued to exceed the critical value with a confidence level ($\alpha$ = 0.01), suggesting that sediment load significantly increased. The UF and UB curve intersections of midstream sediment were in 1974, 1976, 1978 and 2014, and they both located between the 95% confidence lines. The Yamamoto test showed that 1974 and 1976 were false abrupt times, and the SNR of 1978 and 2014 both passed 99% confidence level test, in which the SNR value of 2014 was greater than 2, indicating that 1978 and 2014 were the abrupt points for midstream sediment. The M-K statistic sequence UF curve at Xiangjiaba station in the lower reaches showed an increasing trend from 1966 to 2000 (in which sediment increased significantly between 1998 and 2002) and then a decreasing trend since 2000. The annual average M-K statistics from 2014 to 2016 exceeded the critical value with confidence level ($\alpha$=0.05), indicating that sediment load was significantly reduced. The intersection of downstream sediment UF and UB curves was in 2012, located between the 95% confidence lines. The Yamamoto test showed that the SNR was 2.105 and pass 99% confidence level test, indicating that 2012 was the strong downstream abrupt time. In general, the sediment load abrupt times in the Jinsha River are quite different from upstream to downstream. The upstream sediment abrupt time was in 1987, while the midstream abrupt time is in 1978 and 2014, and the downstream sediment abrupt time was in 2012.

### 2.3 Relationship between cumulative runoff and cumulative sediment load

Runoff and sediment double mass curve are shown in Figure 5. The double mass curve slope for the upstream Shigu station changed little during the study period. From 1975 to 1979, the curve deflected slightly towards the radial axis and the sediment load decreased. The slope increased slightly from 1997 to 2003 and the sediment increased in this period. At the Panzhihua station (midstream), the cumulative curve was slightly deflected towards the radial axis between 1974 and 1980; sediment decreased during this period. The slope of the curve increased from 1997 to 2002 and the cumulative sediment accelerated. After 2010, the curve was significantly deflected to the runoff axis, the sediment was reduced and the cumulative sediment clearly slowed down. Downstream, at the Xiangjiaba station, the double mass curve approximated a straight line before 1993. From 1993 to 2000, the slope of the curve increased and the amount of sediment increased. The slope began to decrease gradually in 2000 and the curve deflected sharply towards the runoff axis after 2010. The cumulative sediment decreased sharply. Totally, the runoff and sediment conditions in the Jinsha River were relatively stable before 1990. From 1993 to 2002, the slope of the cumulative curve at each station increased to varying degrees and the sediment load visibly increased. After 2010, the slope of the cumulative curve in the middle and lower reaches of the river shifted obviously towards the runoff axis and the cumulative sediment decreased rapidly.

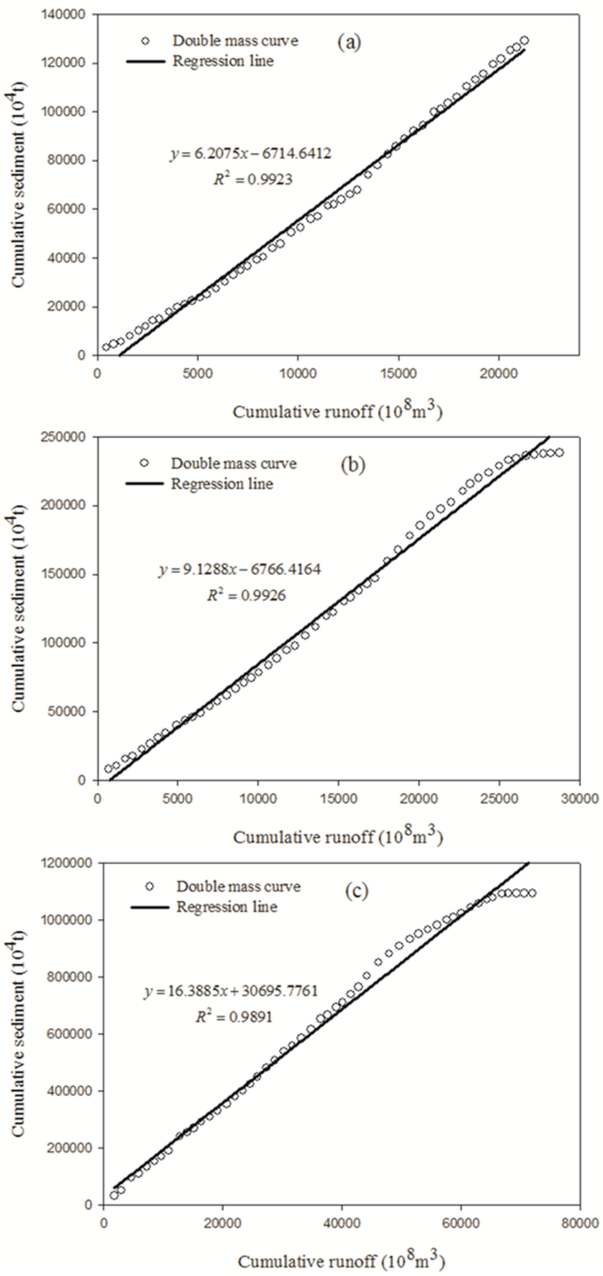


**Figure 5** Runoff and sediment cumulative analysis of three control stations, Shigu (a), Panzhihua (b), Xiangjiaba (c) in 1966 - 2016.

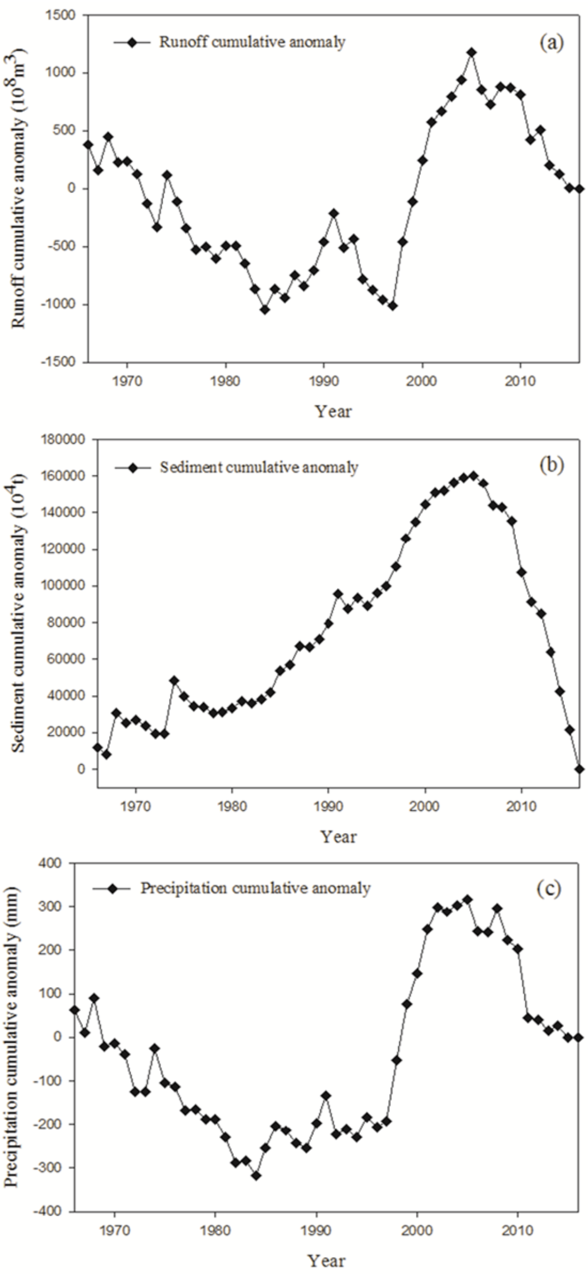


**Figure 6** Turning points of runoff (a), sediment (b) and precipitation (c) in the Jinsha River Basin in 1966 – 2016.

### 2.4 Effect of rainfall and Human activities on runoff and sediment variation

Human activities mainly include reservoir construction and soil and water conservation measures. Since exact values of soil and water conservation measures are difficult to quantify, this study only discusses the comprehensive contribution of human activities. Firstly, according to the cumulative anomaly method, the turning point time for calculating the interannual variation of runoff and rainfall was 1984 and 2005, respectively, and the turning point time of sediment load was found to be 2005 (Figure 6). Secondly, according to the abrupt times of 1984 and 2005, the study period was divided into 3 periods by the slope change ratio of cumulative quantity method, namely the referenced base period of 1966-1984 (RP), the first compared period of 1985-2004 (FP), and the second compared period of 2005-2016 (SP). Considering that the Jinsha River Basin was relatively less affected by human activities during the RP, it can be determined that the RP forms the base period for the study. Finally, based on the slope change ratio of cumulative quantity method, the contribution rate of rainfall and human activities to the runoff and sediment variation in the Jinsha River Basin can be calculated ($R$>0.95, $P$<0.01) .

Table 4 shows the contribution rate of human activities and rainfall to runoff variation calculated by slope change ratio of cumulative quantity method. When the FP is compared with the RP, the slope of the cumulative runoff-year linear relationship increased by 15.63×10$^9$ m$^3$/a and the slope increase rate was 11.7%. The slope of the cumulative rainfall-year linear relationship increased by 50.57 mm/a and the increase rate was 6.9%. The rainfall contributed 59.4% to the increase of the runoff and thus the contribution rate of human activities was 40.6%. When the SP is compared with the RP, the slope of the cumulative runoff-year relationship decreased by 3.09×10$^9$ m$^3$/a with a reduction rate of 2.3%. Rainfall contributed 74.1% and thus human activities contributed 25.9%. When the SP is compared with the FP, the slope of the cumulative runoff-year relationship decreased by 18.72×10$^9$ m$^3$/a with a reduction rate of 12.5%. The contribution rate of rainfall was 64.6%, while the contribution rate of human activities was 35.4%. During the study period, rainfall changes dominated the variation in runoff. The slope of the cumulative runoff-year linear relationship experienced an initial rise but then fell and the slope in the FP was the largest.

Table 5 shows the contribution rate of human

**Table 4** Contribution rate of precipitation and human activities to runoff variation. CR= Cumulative runoff-year linear slope; SC=Slope change; C_human= Contribution of human activities; C_rainfall=Contribution of rainfall.

| Period | CR (10$^8$m$^3$/a) | Compared with period in 1966-1984 | | | |
|---|---|---|---|---|---|
| | | SC (10$^8$m$^3$/a) | SC (%) | C_rainfall (%) | C_human (%) |
| 1966-1984 | 1339.3 | _ | _ | _ | _ |
| 1985-2004 | 1495.6 | 156.3 | 11.7 | 59.4 | 40.6 |
| 2005-2016 | 1308.4 | -30.9 | -2.3 | 74.1 | 25.9 |
| Period | CR (10$^8$m$^3$/a) | Compared with period in 1985-2004 | | | |
| | | SC (10$^8$m$^3$/a) | SC (%) | C_rainfall (%) | C_human (%) |
| 1966-1984 | 1339.3 | _ | _ | _ | _ |
| 1985-2004 | 1495.6 | _ | _ | _ | _ |
| 2005-2016 | 1308.4 | -187.2 | -12.5 | -64.6 | 35.4 |

**Table 5** Contribution rate of precipitation and human activities to sediment variation. CS=Cumulative sediment-year linear slope; SC=Slope change; C_human= Contribution of human activities; C_rainfall=Contribution of rainfall.

| Period | CS (10$^4$t/a) | Compared with period in 1966-1984 | | | |
|---|---|---|---|---|---|
| | | SC (10$^4$t/a) | SC (%) | C_rainfall (%) | C_ human (%) |
| 1966-1984 | 25362 | _ | _ | _ | _ |
| 1985-2004 | 25362 | 0.00 | 0.00 | _ | _ |
| 2005-2016 | 9101.40 | -16260.6 | -64.1 | 2.7 | 97.3 |
| Period | CS (10$^4$t/a) | Compared with period in 1985-2004 | | | |
| | | SC (10$^4$t/a) | SC (%) | C_rainfall (%) | C_ human (%) |
| 1966-1984 | 25362 | _ | _ | _ | _ |
| 1985-2004 | 25362 | _ | _ | _ | _ |
| 2005-2016 | 9101.40 | -16260.61 | -64.1 | 12.6 | 87.4 |

activities and precipitation to sediment load variation calculated by slope change ratio of cumulative quantity method. When the FP is compared with the RP, the slope of the cumulative sediment-year correlation line remained unchanged. This indicates that human activity offsets the impact of increased rainfall. When the SP is compared with the RP and FP, the slopes were both reduced by $162.66\times10^6$ t/a and the reduction rates were both 64.1%. When the SP compared with the RP, rainfall contribution rate was 2.7% and thus the human activity contribution rate reached 97.3%. However, when the SP compared with the FP, the rainfall contribution rate was 12.6% and the contribution rate of human activities was 87.4%. In general, the slope of the cumulative sediment-year correlation line in the Jinsha River Basin is larger than that of runoff, and human activity is the decisive factor in sediment load variation.

## 3 Discussion

### 3.1 Effect of rainfall on runoff and sediment load

Rainfall change dominated the variation in runoff in the Jinsha River Basin and it also had a significant impact on the sediment conditions. Rainfall is the main source of runoff and the main cause of sediment production. The amount of rainfall, as well as its spatial and temporal distribution, determines the runoff and sediment load. Under certain surface conditions, the larger the rainfall and higher intensity, the greater the runoff and sediment load (Hu et al. 2010). The average annual precipitation in the Jinsha River Basin was 753 mm, and over 80% of heavy rains were concentrated in the flood season from May to October during the year. The spatial distribution of precipitation shown an increasing trend from upstream to downstream, and the precipitation in downstream is high and the heavy rain is concentrated in period of June to September (Chen et al. 2008). The maximum precipitation during the study period was 891 mm in 1998 and the minimum value was 590 mm in 2011 (Lu et al. 2016; Shi et al. 2016; Xi et al. 2017). We used M-K trend analysis to test the rainfall trends and the results showed that the M-K test value of rainfall during the period was 1.235, which did not reach the critical value of $\alpha$=0.05 and showed no significant increasing trend (Figure 7), this result was consistent with the findings of Lu et al. (2016). The sequence of MK statistic for precipitation and runoff was basically the same. In 2001-2005, the MK values of precipitation and runoff exceeded the critical value of 1.96, showing a significant increase trend, while the statistical sequence of sediment load showed a rapid decline after 2000.

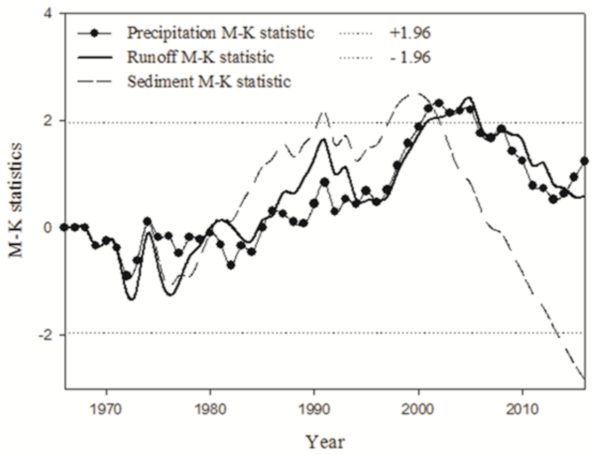


**Figure 7** M-K statistical value sequences for annual precipitation, runoff and sediment load in the Jinsha River Basin in 1966 – 2016.

Pearson correlation analysis showed that the correlation between rainfall and runoff reached 0.783 and the correlation with sediment load was 0.501. The three variables changed strongly and consistently. During the year, the runoff and sediment load in the flood season accounted for 68.2%-80.2% and 85.5%-98.2% of the whole year, respectively. The correlations between precipitation and runoff in the three periods of 1966-1984, 1985-2004 and 2005-2016 reached 0.845 ($P$<0.01), 0.786 ($P$<0.01), and 0.729 ($P$<0.01), respectively. Precipitation and runoff showed significant positive correlations in each period. According to the slope change ratio of cumulative quantity method, the average annual precipitation increased by 47.6 mm, the annual runoff increased by $15.63\times10^9$ $m^3$ and the contribution of rainfall to runoff reached 59.4% (comparing the period 1985 to 2004 with the base period of 1966 to 1984). And in the period of 2005-2016, rainfall dropped by 7.2%, while the runoff decreased by 11.8%. The contribution of precipitation to runoff reached 64.6%. The correlations between precipitation and sediment load in the three periods of RP, FP and SP reached 0.846 ($P<0.01$), 0.607 ($P<0.01$) and 0.269 ($P>0.05$), respectively. Precipitation and sediment showed a high consistent change before 2004. When the FP compared to the RP, the rise of average annual precipitation is accompanied by a rise of 29.58×10$^6$ t of sediment load. The increase in precipitation and runoff has led to a significant increase in sediment load and this is particularly evident in the mid to upstream regions, which are seldom disrupted by human activities. When the FP and SP are compared to the RP, then the average annual sediment load at Shigu could be seen to have increased by 956.58×10$^4$ t and 971.41×10$^4$ t, respectively. After 2005, its correlation coefficient dropped significantly to only 0.269, indicating that the impact of human activities such as the construction and operation of cascade reservoirs was very significant. Monitoring and analysis of rainfall changes in the Jinsha River Basin could provide a scientific basis for the study of runoff and sediment variation trends.

### 3.2 Effect of reservoir on sediment load reduction

Due to the water storage effect of the cascade reservoirs in the Jinsha River Basin, the sediment-blocking effect is significant and the sediment output is greatly reduced. When rivers are affected by reservoir impoundment, the runoff and sediment load often changes significantly. Reservoir construction and operation not only reduces sediment output (Zhao et al. 2014; Shi et al. 2017) but it also changes the relationship between runoff and sediment in the basin (Zhang et al. 2017; Kong et al. 2015; He et al. 2016). Since the impoundment of the Ertan Reservoir on the Yalong River in 1998, the development of hydropower in the Jinsha River Basin has accelerated rapidly and the impact of reservoir construction on sediment load has become more significant, especially after 2010. The Jinanqiao and Liyuan reservoirs in the midstream and a series of downstream reservoirs (such as those at Xiangjiaba and Xiluodu), have showed obvious sediment-blocking effects. Thereby, the sediment load in the middle and lower reaches is significantly reduced and the characteristics of runoff and sediment in these areas have clearly changed.

The results of this study show that when the period of 2005 to 2016 is compared to the periods of 1966 to 1984 and 1985 to 2004, the contribution rate of human activities to sediment reduction reached 97.3% and 87.4%, respectively. This is far greater than the impact of changes in precipitation. Actual monitoring results also indicate that since the successive operations of the cascade reservoirs commenced in the middle and lower reaches (during 2011 to 2015), the sediment load at the midstream control station Panzhihua decreased from an annual average of 47.70×10$^6$ t to 8.87×10$^6$ t between 2011 and 2016; the rate of decrease reached 81.4%. Since the Xiangjiaba and Xiluodu reservoirs started operating downstream (from 2012 and 2013, respectively) the two reservoirs intercepted 421×10$^6$ t of sediment and the combined sediment discharge ratio was 1.6%. The amount of sediment at Xiangjiaba station decreased from 223×10$^6$ t per year to 1.75×10$^6$ t per year from 2013 to 2016, with a decrease rate of 99.2%. The research results show that the contribution of cascade reservoirs to sediment reduction in the Jinsha River is significant.

Reservoir impoundment and sediment interception also changed the characteristics of runoff and sediment under the Xiangjiaba station. The construction of a series of cascade reservoirs in the Jinsha River Basin has greatly reduced the sedimentation from the Jinsha River into the Three Gorges Reservoir. Zhu et al. (2016) found that the sediment coming from the Jinsha River between 2003 and 2012 was reduced by 101×10$^6$ t, accounting for 34.0% of the sediment reduction being transported into the Three Gorges Reservoir. In 2014, after the impoundment at Xiluodu and Xiangjiaba, the sediment load at Xiangjiaba station decreased by 140×10$^6$ t, accounting for 94.7% of the sediment reduction being transported into the Three Gorges Reservoir. On the other hand, the drastic reduction of sediment has caused a change in the characteristics of scouring and silting, resulting in sharp erosion between the Xiangjiaba and the Yibin section, the sediment yield downstream increasing. Changes in the erosion and deposition under the dam may pose a threat to the safety of downstream river sections and these issues need to receive attention in future work.

### 3.3 Effects of soil and water conservation measures

Various soil and water conservation measures in the Jinsha River Basin have played a positive role in some respects but the sediment output in some areas is still a serious issue. Soil and water conservation measures can effectively curb the output of sediment and improve regional water and soil conservation capacity (Fu et al. 2017). The control of soil erosion in the Jinsha River Basin began with the implementation of the first phase of the "Changzhi" project in 1989 and then the natural forest protection project was initiated in the middle and lower reaches of the Jinsha River in 1998. Xu et al. (2004) carried out analysis using the water conservation method and hydrological method and found that the average annual sediment reduction of the "Changzhi" project in Jinsha River Basin from 1991 to 2005 was between $960\times10^6$ t and $1460\times10^6$ t. Other relevant research also showed that, with the implementation of many water and soil conservation projects such as the "Changzhi" Project, since 2000 the surface vegetation in the middle and upper reaches of the Jinsha River Basin had shown a significant increase. In the downstream areas, vegetation coverage had visibly increased, sediment output had declined and high soil and water conservation benefits had been obtained (Xu 2009; Wang et al. 2016). This is consistent with the results of this research: the contribution rate of human activity (mainly for soil and water conservation) to runoff increased by 40.6% during the period 1985 to 2004.

In recent years, however, the survey also found that the vegetation degradation in the middle and upper reaches of the Jinsha River Basin on the western Sichuan Plateau had not improved and even deteriorated with the development and utilisation of the Jinsha River (Wang et al. 2012). As the main source of sediment load, the output of the section from Panzhihua to Xiangjiaba (excluding the Yalong River) accounts for 63.3% of the total basin. The sloping farmland on both sides of the river valley in this region has suffered serious soil erosion. With arable land being returned to forests in the second subsidy period in recent years, the subsidy has declined and the returned forest has had a low benefit. In recent years, steep slopes area or forests have been opened up for farmland in some areas. On the other hand, the exploitation and utilisation of various resources in the region (as well as engineering construction, mining, large-scale hydropower construction) has led to soil erosion, debris flows and landslides. At present, the sediment output in these areas is still very high, indicating that the soil and water loss is still relatively serious and it will be a key area for future water and soil conservation work.

## 4 Conclusions

(1) The spatial heterogeneity of runoff and sediment is significant in the Jinsha River Basin. The runoff mainly comes from the Yalong River and the upper reaches of the Jinsha River, which accounts for 71.4% at Xiangjiaba station. 63.3% of the total sediment comes from the section between Panzhihua and Xiangjiaba (excluding the Yalong River).

(2) The runoff trend in the Jinsha River Basin shows a non-significant increase. The variation of sediment load is more complicated with sediment load significantly increasing in the upper reaches, increasing in the middle reaches and significantly decreasing in the lower reaches. The variation coefficient of sediment load is between 0.437 and 0.531, which is more intense than that of runoff.

(3) M-K analysis indicates that the runoff in the Jinsha River Basin showed an increasing trend but that the trend was not significant. The upstream and midstream runoff abrupt times were both in 1985 and the downstream abrupt times were in 1980 and 2013. In terms of sediment load, the trend and abrupt point time of the sediment load differed between stations. The upstream showed an abnormally significant increasing trend, the midstream was not significantly reduced, but downstream was significantly reduced. The upstream sediment load abrupt point time was in 1987, the middle reaches were in 1978 and 2014 and the downstream was in 2012.

(4) Rainfall contributed more than 59.0% to the runoff increase and human activities contributed more than 87.0% of the sediment load reduction when the periods of 1985-2004 and 2005-2016 are compared to the base period of 1966-1984.

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