

Periodicity and Multi-scale Analysis of Runoff and Sediment Load in the Wulanghe River, Jinsha River

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Abstract. Based on the annual runoff and sediment data (1959–2014) of Zongguantian hydrological station, time-frequency wavelet transform characteristics and their periodic rules of high and low flow alternating change were analyzed in multi-time scales by the Morlet continue wavelet transformation (CWT). It is concluded that the primary periods of runoff and sediment load time series of the high and low annual flow in the different time scales were 12-year, 3-year and 26-year, 18-year, 13-year, 5-year, respectively, and predicted that the major variant trend of the two time series would be gradually decreasing and been in the high flow period around 8-year (from 2014 to 2022) and 10-year (from 2014 to 2020).

1. Introduction

Runoff and sediment load, as the basic elements of hydrological element, play an important role in the fluvial morphology through time and space, sustaining the riverine ecosystems and biodiversity [1, 2]. Jinsha River is located in the Qinghai-Tibet Plateau and North Yunnan Plateau of China. As it is the headwater of the Yangtze River, the changes of runoff and sediment load have attracted considerable attention. Chen *et al.* [3] after analysing the sediment loads and annual runoff data of different sections on the Jinsha River, indicated that the runoffs and sediment loads of the lower reaches is relatively higher than the upper ones, showing different variation characteristics.

Wulang River is an important tributary of the Jinsha River, originates in the northeastern part of the Ninglang region of Lijiang city, northwestern Yunnan province, and flows to the southeast to enter the Jinsha River. Being the most important river in Lijiang, it is essential to take advantage of the abundant water resources of Wulang River to construct water conservancy project, which is an important content of the development and management on Wulang River basin in the future.

Although, there have been existed many researches on the discussions of runoff and sediment loads changes in the Jinsha River [3-7], the majority of previous studies focused on the variations of runoff or sediment discharge in main sections to seek out the effect of the changes on the Yangtze River, fewer analyses have been conducted along the headwater area or tributaries, especially related to Wulang River. Thereafter, the aims of this study is examining changes in the periodicity of runoff and sediment load over the period 1959–2014.



2. Study area

The Wulanghe River originates in the northeastern part of the Ninglang county of Lijiang city, northeastern Yunnan province, and flows to the southwest to enter the Jinsha River, across the northern Yongsheng county of Lijiang city (Fig.1). The main stream is 98.1 km long and it drains a catchment of 2,088 km² entirely located on the midstream of the Jinsha River, and the watershed elevation is 3000m a.s.l. The annual mean temperature ranges from 6.4°C to 19.5 °C, and the annual mean precipitation is 951mm. Regarding water resources, the annual mean streamflow is $8.97 \times 10^8 \text{ m}^3$ in total. The annual mean sediment discharges are $2.37 \times 10^6 \text{ t}$.

3. Data and methods

3.1. Data

The annual streamflow and sediment load data for 56 years (from 1959 to 2014) observed at the Zongguantian hydrologic station, which is the control station of water and sediment of Wulang River into Jinsha River, were used in this study (Fig.1). Both of the annual runoff and sediment load data were standardized by SPSS statistical software.

3.2. Method

Wavelet analysis (WA), as a useful mathematical tool for detecting hydrologic alterations at multiple temporal scales simultaneously, has been increasingly used to examine the variability of hydrological time series in recent years [8-13]. Wavelet transform composed of Discrete Wavelet Transform (DWT) and Continuous Wavelet Transform (CWT). The former is used for noise reduction and data compression processing, while the latter is suitable for extracting signal features. Therefore, CWT is adopted in this study to decompose the hydrological series into time-frequency space to determine both the dominant modes of variability and how those modes vary in time [14]. The concept and procedure of the wavelet method theory are thoroughly explained and discussed by Torrence & Compo [14].

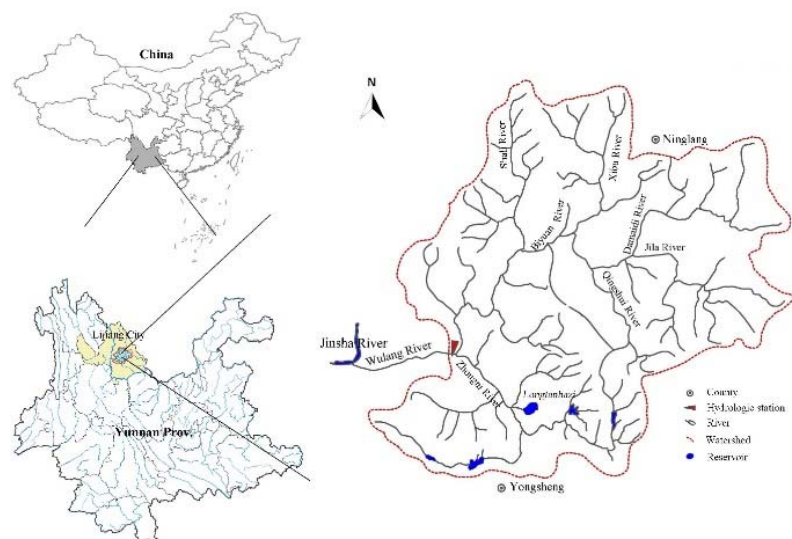


Figure 1. Location of Wulang River Basin

4. Results and Discussion

The normalized runoff and sediment load at Wulang River during the period of 1959–2014 are transformed by using the Morlet CWT, and the resulting wavelet coefficient information, such as real part, wavelet power spectrum and variance, are shown in Fig. 2 and Fig. 3, respectively.

4.1. Real Part of Wavelet Coefficients

The real part of CWT coefficients can be used to detect the periodic variation of time series at different time scales and its distribution, showing trend of time series at different time scales in the future. The Isopleth maps of real part for the normalized runoff and sediment load are shown in Fig. 2a and Fig.2b, respectively. Both of the two time series showed an obvious interannual (less than 10 years) and interdecadal variation (more than 10 years), that is, from large scale to small scale (from top to bottom):

For annual runoff (Fig.2a), there exist two prominent scales of periodic variation: 6- to 28-year band and 2- to 5-year band, showing alternate variations of runoff obviously. As for 6- to 28- years band, the runoff experience two oscillations varying with time, presents obvious mutation characteristics, that is, 1959–1964 are dry, 1968–1976 wet, 1984–1998 dry, and 2002–2014 wet. The 6- to 28-year band dominates the whole yearly runoff series. While the 2- to 5-year band experience the periodic model of “dry-wet-dry” during 1960–2000.

As for the sediment load (Fig.2b), different changing patterns can be identified compared to the runoff. There exist four conspicuous scales of periodic variation: 24- to 28-year, 14- to 20-year, 10- to 12-year, and 4- 8-year band, dominates the whole yearly runoff series. At the 24- to 28-year scale, the sediment load presents four oscillations of “lower-higher”, with the main central point around 26-year, indicated prominent mutation characteristics. When it comes to 14-20 years band, there exist five oscillations of “lower-higher”. Besides, the strongest oscillation in the whole sediment load series appears in this range, especially in the period of the 1990–2000. Differ from the larger time scales mentioned above, the periodic variation of the 10- to 12-year and 4- to 8-year band exhibiting localization to varying degrees, which presents three and five oscillations of “higher to lower” during 1960–1980 and 1980–2000, respectively.

In general, the periodic variation of runoff and sediment load time series are not consistent, however, the larger time scale of runoff (6- to 28-year band) contains the largest three periodic variation of sediment load (24- to 28-year, 14- to 20-year and 10- to 12-year band), while the smaller one of runoff (2- to 5-year band) is partially consistent with sediment load (4- to 8-year band). It should be noted that the strongest oscillation of the whole two time series appears approximately at 12-year band, which might be related to the sunspots cycle.

4.2. Wavelet Power Spectrum

The continuous wavelet power spectrum for the time series of annual runoff (Fig. 2c) show a high wavelet power in the 8- to 18-year band after 2000 year. Besides, another significant 2- to 5-year band is distributed around 1959–1966. As for the continuous wavelet power spectrum of the sediment load (Fig. 2d), the significant wavelet power spectra are in the 4- to 6-year band during 1964–1970 and 1995–2002, and in the 12- to 18-year band during 1988–2002. Besides the wavelet power is relatively broadly and uniformly distributed in the 24- to 28-year band along the whole series. Compared to the runoff, there are some common features in the wavelet power such as the significant peak in the 3- to 5-year band around 1964–1966. Both series also have high power in the 12- to 18-year band in the latter years of the whole series, which illustrates the obvious influences of runoff on the sediment load to a certain extent.

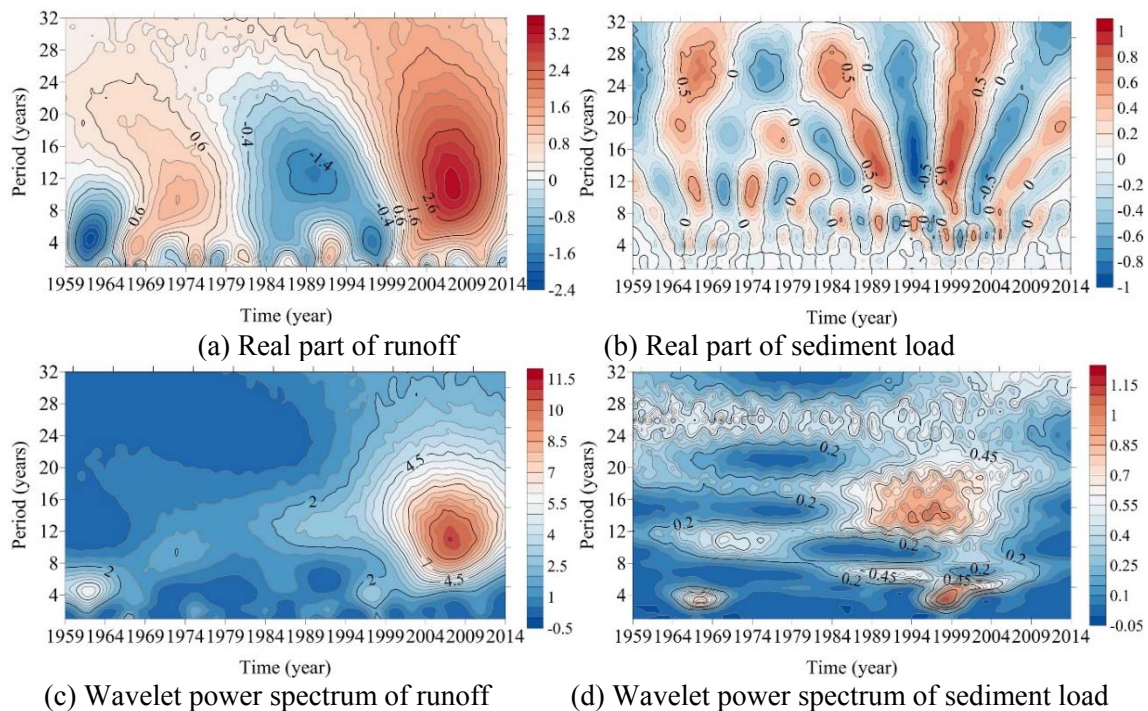
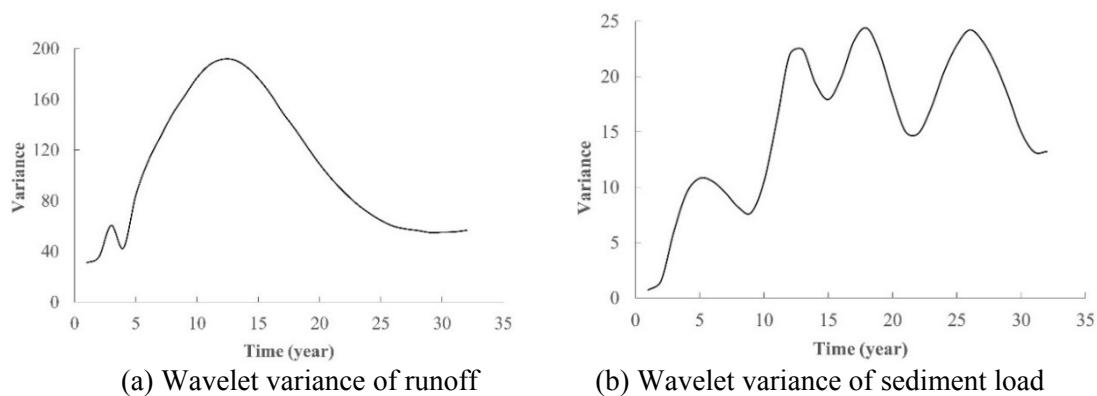
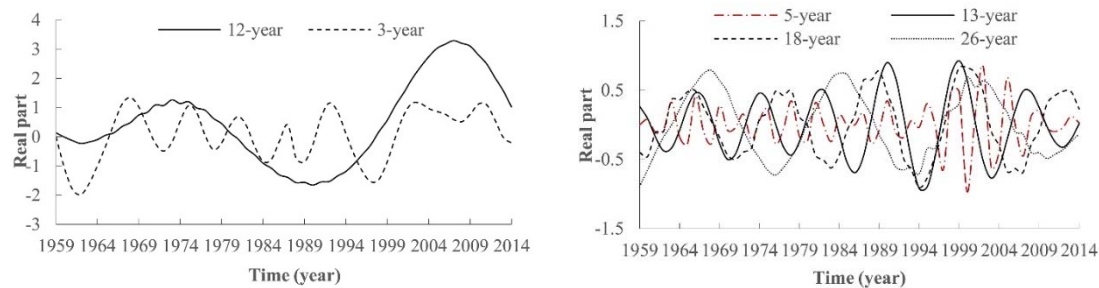


Figure 2. Isopleth maps of CWT coefficients real part (a and b) and wavelet power spectrum (c and d), transformed from the normalized annual runoff and sediment loads data, respectively. The plot has a color scale ranging from blue (low energy) to red (high energy). Note that periods with real part value > 0 are characterized by a higher energy in stream flow, while the contrary is observed for real part value < 0 .

4.3. Wavelet Variance Test

The wavelet variance of CWT can be used to test the primary period of the time series by seeking the peak of the series. The wavelet variance of the annual runoff (Fig. 3a) obviously shows two different peaks of the time series, the stronger one at 12-year time scales and the minor one at 3-year, that is to say, the primary and secondary period of the runoff series are 12-year and 3-year scales, respectively. Similarly, the primary and secondary period of the sediment load series (Fig. 3b) are 18-year, 26-year, 13-year and 5-year scales (from strong to weak), corresponding to the four peaks of series. Significantly, the former two primary periods (18-year and 26-year) almost appear to be at the same high level of the wavelet variance. The results of the test for the two time series are consistent with the conclusion of wavelet power spectrum analysis in Section 4.1.2.





(c) Wavelet real parts under different scales of runoff (d) Wavelet real parts under different scales of sediment load

Figure 3. Wavelet variance diagram (a and b) and wavelet real parts under different scales (c and d) of runoff and sediment loads series data. The positive value of real part on the picture designates the runoff is more and vice versa. Note that periods with real part value > 0 are characterized by a higher energy in stream flow, while the contrary is observed for real part value < 0 .

4.4. Runoff and Sediment Load Variation under Different Periods

The real part of CWT coefficients under different primary period of runoff series data is shown in Fig. 3b, which reveal that the runoff experienced about 2 and 5 cycles on the whole series at 12- and 3-year periods, respectively. At the period of 12-year, the whole runoff series started to change from dry to wet at 1964–1965, then turned into dry at around 1980–1981. After 1997, the runoff series transformed into wet years, and the maximum value of the fluctuation appeared at around 2007, which is agree with the highest wavelet power distribution at 2007 in Fig. 2c. Likewise, the mutations of the runoff series at 3-year period are: 1965–1966 (dry to wet), 1970–1971 (wet to dry), 1973–1974 (dry to wet), 1977–1978 (dry to wet), 1979–1980 (wet to dry), 1982–1983 (wet to dry), 1986–1987 (from dry to wet), 1987–1988 (wet to dry), 1990–1991 (from dry to wet), 1994–1995 (wet to dry), 2000–2001 (from dry to wet) and 2012–2013 (wet to dry). Furthermore, both of the two periods showing a decreasing trend after 2014, predicted that the runoff will be turned into wet year at around 2018 (3-year period) and 2022 (12-year period), respectively.

Similarly, the real part of CWT coefficients under four different primary periods of sediment load (Fig. 3d) showing the sediment load had about 3, 5, 7.5 and 17 oscillations on the whole series at 26-, 18-, 13- and 5-year periods, respectively. As for 26-year period, there exist six mutations: 1963–1964 (less to more), 1971–1972 (more to less), 1979–1980 (less to more), 1988–1989 (more to less), 1996–1997 (less to more) and 2005–2006 (more to less). The detailed mutations of the other three periods won't be described here due to the limited space. In addition, the tendency at the four primary periods are not consistent, such as 26-, 13- and 5-year periods present increasing trend after 2014, while at 18-year the trend is contrary, which demonstrated that the internal variation trend of time series can be detect by using the wavelet analysis method.

5. Conclusion

The sediment load and runoff are the key components of the fluvial system. Being the most important river in Lijiang region, it's urgent to study the runoff and sediment load changes in order to make more reasonable utilization of the water resource of Wulang River basin. In this study, the variability of the sediment load and the runoff of Wulang River basin are analysed using the continuous wavelet approach. The following points can be concluded from the study:

(1) The real part of CWT coefficients of the annual of runoff and sediment load showed an obvious interannual and interdecadal variation. The different prominent scales of runoff and sediment load periodic variation are: 6- to 28-year, 2- to 5-year band and 24- to 28-year, 14- to 20-year, 10- to 12-year, 4- to 8-year band, respectively, demonstrated that though the prominent scales of runoff and sediment load intersection are inconsistent, there exist some links between them. Continuous wavelet power spectrum analysis results indicate that the annual runoff and sediment load are dominated by the 8- to

18-year, 2- to 5-year periods and 4- to 6-year, 12- to 18-year periods, respectively. Wavelet power relations and phase relations between the two series are relatively stable in 12- to 18-year periods in the latter years of the whole series, demonstrating that the obvious influences of runoff on the sediment load.

(2) The primary periods of the annual runoff and sediment load series are 12-year, 3-year and 18-year, 26-year, 13-year and 5-year scales, respectively. The results of the test for the two time series are consistent with the conclusion of wavelet power spectrum analysis. The primary periods of the annual runoff showing a decreasing trend after 2014, predicted that the runoff will be turned into wet year at around 2018 (3-year period) and 2022 (12-year period), respectively. While 26-, 13- and 5-year periods of sediment load series present increasing trend after 2014, and at 18-year period the trend is contrary, which demonstrated that the internal variation trend of time series can be detect by using the wavelet analysis method.

(3) The continuous wavelet transform and the cross wavelet analysis of sediment load indicates that runoff can only explain part of the variation of sediment load, and other factors, especially human activities (e.g. land-use changes, dam construction), should be considered sufficiently in further research. Furthermore, the time series data selected in this paper is annual, and the details of the variation of runoff and sediment load in shorter time scales (seasonal or monthly) is out of the scope of the current research.

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