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Original Research

A Study on the Variations and Relationships between Water and Sediment in the Longchuan River, China

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Abstract

Runoff and sediment transport rates are important indicators for guiding regional economic development and ecological protection. It is important to clarify the dynamic evolution processes and inner connection of runoff and sediment transport rate for the rational development of soil and water resources in Longchuan River. In this study, the Mann-Kendall test, wavelet analysis and synchronization analysis have been used to analysis the change trend, mutation situation and variation cycles of runoff and sediment transport rate. The results showed that: runoff volume was generally stable, and sediment transport rate experienced a significant increasing trend at a rate of 4.29 kg/s/a in 1970-2008 in Longchuan River. The change cycles of runoff volume and sediment transport rate were different. The first principal cycles of seasonal and annual runoff volume were all 25a, while the second and third principal cycles were different. In contrast, the first and second principal cycles of sediment transport rate were respectively 29a and 6a. There was a significant linear relationship between sediment transport rate and runoff although the relationship between water and sediment was only synchronous in 1991-2008.

Keywords: runoff volume, sediment transport rate, relationship of water-sediment, wavelet analysis, Longchuan River

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Introduction

Runoff and sediment are important indicators that reflect the health status of a river and essential basis for maintaining river ecosystem, which directly affect the development and utilization of water and soil resources of rivers and their basins [1]. As the increasing intensity of global climate change and human activities, the change and evolution of relationship between runoff and sediment in rivers can increase the probability of droughts and floods in regions [2]. At the same time, the imbalance of water-sediment relationship can not only threaten the water quality security, exacerbate contradiction with water utilization, but also seriously hinder the reasonable development of hydropower resources so that affects the socio-economic development and social stability [3-5].

Hydrologic data is a kind of time series data which often does not fit the normal distribution and has outliers and missing values. Hence, the nonparametric test method Mann-Kendall test is usually used to examine the trends and abrupt changes of hydrological data in a river, and the wavelet analysis is used to detect the periodic changes of runoff and sediment in a river [6, 7]. Due to the maturity of Mann-Kendall test and wavelet analysis, the two methods have been used by many scholars in studying the relationship between precipitation, runoff and sediment yielding in a watershed [3, 4, 6, 8-10]. For example, Shi et al. [1] analyzed the change process of annual runoff and sediment discharge through Mann–Kendal trend test and rank sum test in the Yellow River during 1950-2014, and found that all the two decreased significantly with the time. The reasons why runoff decreased were the reduction of precipitation and the increase of water consumption and the reduction of sediment discharge resulted from the environmental conservation and dam construction. Zhao et al. [11] studied the water discharge and sediment load in the mainstream and seven tributaries of the Yangtze River according to the results of non-parametric Mann-Kendall test and double mass curve, and analyzed the main reasons. And the results showed that the water discharge was mainly influenced by precipitation in the Yangtze River Basin, whereas sediment load was mainly affected by climate change and human activities; the relative contribution ratios of human activities were above 70% for the Yangtze River. Moreover, Liu et al. [12] analyzed the change trend of runoff and sediment in Taojiang from 1957 to 2015 using Mann-Kendall method, cross-wavelet, and wavelet coherence analysis method, and found that the decrease of runoff and sediment was mainly because the construction of large-scale hydro-power stations.

Longchuan River is a first-class tributary of the south bank of Jinsha River, located in the old arid zone of central Yunnan. And the typical Yuanmou dry-hot valley region located in the downstream of Longchuan River. Yuanmou dry-hot valley region is featured with hot climate and little rainfall, fragile ecological environment and serious soil erosion. The harsh natural environment coupled with man-made indiscriminate logging, animal husbandry and farming have resulted in serious soil erosion, and most of the eroded sediment directly entered into the Longchuan River which largely threated the river's health. The Longchuan River Basin is not only an important economic zone in central Yunnan, but also a key water and sand production area in the upper reaches of the Yangtze River [13]. It is of great significance to study the characteristics of runoff and sediment transport in the Longchuan River, which not only contribute to understanding the changes of hydrological situation and develop and utilize water and soil resources scientifically and reasonably, but also helpful for carrying out comprehensive management of water and soil erosion in the basin. Therefore, in order to probe the variations and relations between water and sediment in Longchuan River, reliable and in-depth analyses based on detailed data of runoff and sediment from 1970 to 2008 have been conducted to (1) examine the dynamic change process of runoff volume and sediment transport rate and (2) determine the relationship between runoff volume and sediment transport rate in the past decades.

Materials and Methods

Study Area

The study area is located in Longchuan River Basin is in the transition zone between the Hengduan Mountains and the Yunnan-Guizhou Plateau, which extends between 100°56′ E to 102°02′ E and 24°45′ N to 26°15′ N (Fig. 1), and the altitude of study area ranges from 940 m to 3657 m. The Longchuan River is a first-class tributary of the Jinsha River on its southern bank, which originates at the foot of Ludu Mountain in Tianzimiao, Nanhua County, Yunnan province, China, and flows through 10 counties including Nanhua, Chuxiong, Muding, Ciaofeng, Yuanmou, Dajao, Shuangbai, Yaoan, Yongren, Wuding, etc. The Longchuan River merges into Jinsha River in Jiangbian township, Yuanmou County, with a total length of about 246 km and a watershed area of about 9256 km².

The study area features notable dry and wet seasons, with a mean annual precipitation of 847.2 mm, a mean annual temperature of 15.6ºC, and an average annual potential evaporation of 3847.8 mm. The precipitation is concentrated in the rainy season (lasting from June to October), accounting for 85% of the annual precipitation. Due to rainfall is the major source of runoff, the annual variation of runoff is great, which is consistent with the precipitation. The runoff accounts for more than 80% of the annual runoff in rainy season in Longchuan River. In contrast, the runoff in driest months including March and April just account for only 1.1% of the annual runoff. Hence, the coefficient of variation of runoff is very large in a year, and the water production modulus

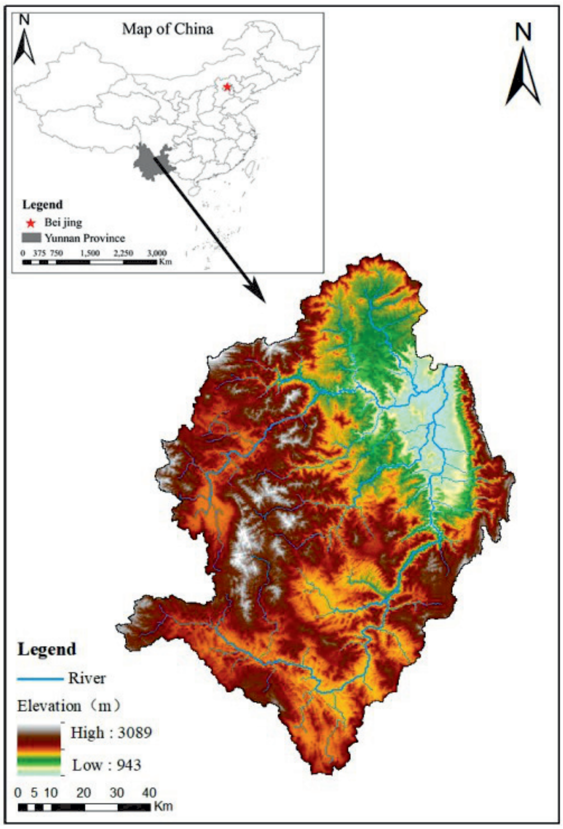


Fig. 1. The geographical location of the study area.

ranges from 15 m^3·km^{-2} to 40 m^3·km^{-2} in the study area [14]. Additionally, the daily temperature difference is very large while the annual temperature difference is very small. Due to the influence of natural geography, the climate in the upper and lower reaches of Longchuan River has distinct difference. It is featured with dry and hot climate in the lower reaches of Longchuan River, while it is humid and cool climate in the upper reaches [15]. In general, the zonal vegetation type is subtropical evergreen broad-leaved forest zone in the whole Longchuan River Basin, whereas it changes into savanna-like, mainly comprising shrubs and grass with few trees and extremely low forest coverage of 0.6% in the downstream dry-hot valley region [16]. The dominate soil types are Purple soils and red soils in the basin [17]. Heavy rainfall is very common in the rainy season and is coupled with a loose structure of the underlying surface, which is Quaternary river and lake deposit sediment, resulting in weak corrosion stability in the underlying surface. Therefore, the soil erosion intensity and sediment content are very high in this basin, especially in the lower reaches, where gully erosion plays a dominant role in overall soil erosion, with an average gully density of 4.5 km·km^{-2} and a maximum density of 7.4 km·km^{-2}, and the soil erosion modulus amounts to 8000~20000 t·km^{-2}·a^{-1} accompanied by maximum sediment transport rate up to more than 360 kg·s^{-1} [18].

Data Collection and Analysis

Due to the difficulty of gaining the long term original raw data of runoff and sediment yielding in Longchuan River, the software of GetData Graph Digitizer has been used to mine the necessary data from previous studies [13, 17], and then the runoff data from 1960 to 2009 and sediment transport rate data from 1970 to 2008 were obtained. In addition, we verified accuracy of the obtained data through comparative analysis between the obtained data and some measured data from Huangguayuan hydrological station. In this study, the Mann-Kendall test and regression analysis have been used to analysis the change trend and detect the abrupt change point, and wavelet analysis has been conducted to determine the variation cycles of runoff and sediment transport rate, meanwhile, the synchronization of runoff and sediment transport rate has also been analyzed in Longchuan River from 1970 to 2008 [19, 20]. The above analyses were performed in Excel 2010, Origin 8.0, Sigmaplot 10.0, Surfer15, and Matlab18b.

Mann-Kendall Trend Analysis and Mutation Analysis

The detailed calculation processes can refer to the studies of Yan et al. (2015) [21], Zhou et al. (2011) [22], Zhao et al. (2020) [23], and Huang et al. (2019) [24]. It will not be repeated here.

Morlet Wavelet Analysis

The wavelet function $\varphi(t)\in L^2(R)$, and $\int_{-\infty}^{+\infty}\varphi(T)dt=0$, where $\varphi(t)$ is the wavelet basis function.

Calculate the sub wavelets: $\varphi_{a,b}(t)=|a|\varphi(\frac{t-b}{a})$, where a represents the period length of the wavelet and b represents the translation factor in time [25].

Synchronicity Analysis

In this study, the synchronicity of runoff and sediment transport rate was identified by the degree of synchronous difference η. The specific calculation method is as follows [26]:

$$\eta=(1-\frac{S_b}{S_a})^2 \tag{1}$$

Where η is the degree of synchronous difference; *Sa* and *Sb* are the change ratios of runoff volume and sediment volume relative to their respective reference periods. The corresponding calculation formula is as follows:

$$S_a=\frac{W_0-W_j}{W_0}\ ;\quad S_b=\frac{W_{s0}-W_{sj}}{W_{s0}} \tag{2}$$

Where W_0 and W_j are the average annual runoff in the base period and the j[th] year, respectively; W_{s0} and W_{sj} are the average annual sediment transport rate in the base period and the j[th] year, respectively.

When Sa = Sb, η = 0, which indicates there is no difference for the change degree between annual runoff volume and sediment transport rate; when Sa→0 and Sb≠0, η→∞, which indicates there is the largest difference for the change degree between the annual runoff volume and sediment transport rate; when Sa≠Sb and Sa≠0, 0≤η<∞, and the larger the η is, the weaker the synchronization between the annual runoff volume and sediment transport rate is. The base period of runoff volume and sediment transport rate in Longchuan River have been determined as the year from 1958 to 1960 by referencing the study results of Yao et al. [26] and taking into account the available data. And the average annual runoff volume (550.96*10^6 m^3) and sediment transport rate (78.76 kg/s) in Longchuan River from 1958 to1960 were used as the benchmark data to calculate the synchronicity of water and sediment in Longchuan River.

Results and Discussion

Results

Annual Variation of Runoff Volume

The annual variation of runoff reflects the change characteristics of rainfall and runoff production in the basin on a certain time scale, and is a process indicator that reflects the change of water resources abundance and shortage in the basin. The regression analysis and Mann-Kendall trend test are important methods for analyzing the variation patterns of rainfall, runoff, and meteorological data over long time series. The results of the regression analysis showed only the runoff volume in spring increased significantly at a rate of 0.649*10^6 m^3/a during 1970-2008 while those in summer, autumn, winter and annual increased insignificantly (Table 1). All this indicates that the runoff volume in the Longchuan River Basin is relatively stable on a quarterly and annual scale except for spring.

In view of the "averaging" property of regression analysis, it generally reflects to the average change trend during the whole study period. To further analyze the fluctuations of runoff volume over the time, the Mann-Kendall test had been used to analyze the changes trend and abruption in spring, summer, fall, winter, and annual runoff. The results showed that there were different increasing trends for runoff volume in all the four seasons and yearly, and only that in spring runoff is significant while the increasing trend in other periods were not significant, which is consistent with the result of regression analysis (Table 2).

To further analyze the variation process of runoff volume under different time scales, the M-K mutation tests were conducted for four seasons and annual runoff volume at significant level and extremely significant level, and the results were shown in Fig. 2. The UF values for spring runoff volume were less than 0 during 1970-2001, indicating a decreasing trend of runoff volume in the Longchuan River during that period. Among them, |UF| values were greater than 1.96 in 1971-1973, 1977-1986, 1989 and 1991, indicating a significant decreasing trend of spring runoff volume in the above years; |UF| values were greater than 2.58 in 1971, 1979-1984, indicating an extremely significant decreasing trend of spring runoff volume in the above years. The UF values of spring runoff volume were greater than 0 during 2002-2008, and the values of |UF| were less than 1.96, which suggested that the increasing trend of spring runoff volume was not significant (Fig. 2a). In addition, it can be found from the Fig. 2a that there was no intersection point between the UF and UB of spring runoff volume from 1970 to 2008, that is to say, there was no abrupt years for spring runoff volume in the Longchuan River during this period.

The UF values of summer runoff volume were less than 0 during 1970 to 1997, in contrast, it turned to be greater than 0 during 1998-2008, which suggested that there were respectively decreasing and increasing trend for runoff volume during 1970 to1997 and 1998 to 2008. Further analysis revealed that the values of |UF| were less than 1.96 from 1970 to 1997 except for 1982-1984 whose |UF| values was greater than 1.96, which demonstrated that the summer runoff volume had a significant decreasing trend only in the year of 1982 to1984 while the increasing or decreasing trend in other years was not significant (Fig. 2b). In addition, the UF and UB of summer runoff volume did not intersect

Table 1. Variation of runoff volume in different time scales in Longchuan River.

Period	Fitting equation	R^2	p	N
Spring	y = 0.649x - 1265.321	0.112	0.037	39
Summer	y = 2.746x - 5021.967	0.011	0.526	39
Autumn	y = 1.580x - 2848.091	0.010	0.548	39
Winter	y = 0.211x - 386.437	0.018	0.417	39
Annual	y = 5.186x - 9521.815	0.018	0.409	39

Table 2. Results of M-K trend test for runoff volume in Longchuan River.

Period	Average runoff volume (10^6 m^3)	Z	Trend	Significance	Confidence
Spring	25.169	1.923	increases	significant	95%
Summer	440.115	0.593	increases	Not significant	
Autumn	294.998	0.520	increases	Not significant	
Winter	33.306	0.508	increases	Not significant	
Annual	793.588	0.605	increases	Not significant	

during 1970 to 2008, i.e., there was no abrupt years for summer runoff volume in the Longchuan River during this period (Fig. 2b).

The UF values of autumn runoff were greater than 0 during 1970 to 1980, 1986 to 1988, 1991 to 1993, and 1995 to 2008, which indicated there were upward trend in runoff volume during these years. In contrast, the UF values of autumn runoff were less than 0 during 1981 to 1985, 1989 to 1990, and 1994, indicating a downward trend in runoff volume during this period. Moreover, because all the |UF| values were less than 1.96 during 1970 to 2008, it indicated that the increasing or decreasing trend of autumn runoff volume were not significant during the study period. Finally, Fig. 2c) also showed that the UF and UB of autumn runoff volume intersected a few times which implied that the autumn runoff volume underwent several abrupt changes during 1970 to 2008.

As for the UF values of winter runoff volume, they were less than 0 from 1970 to1999 and turned to be greater than 0 from 2000 to 2008, which indicated winter runoff volume experienced a decreasing trend

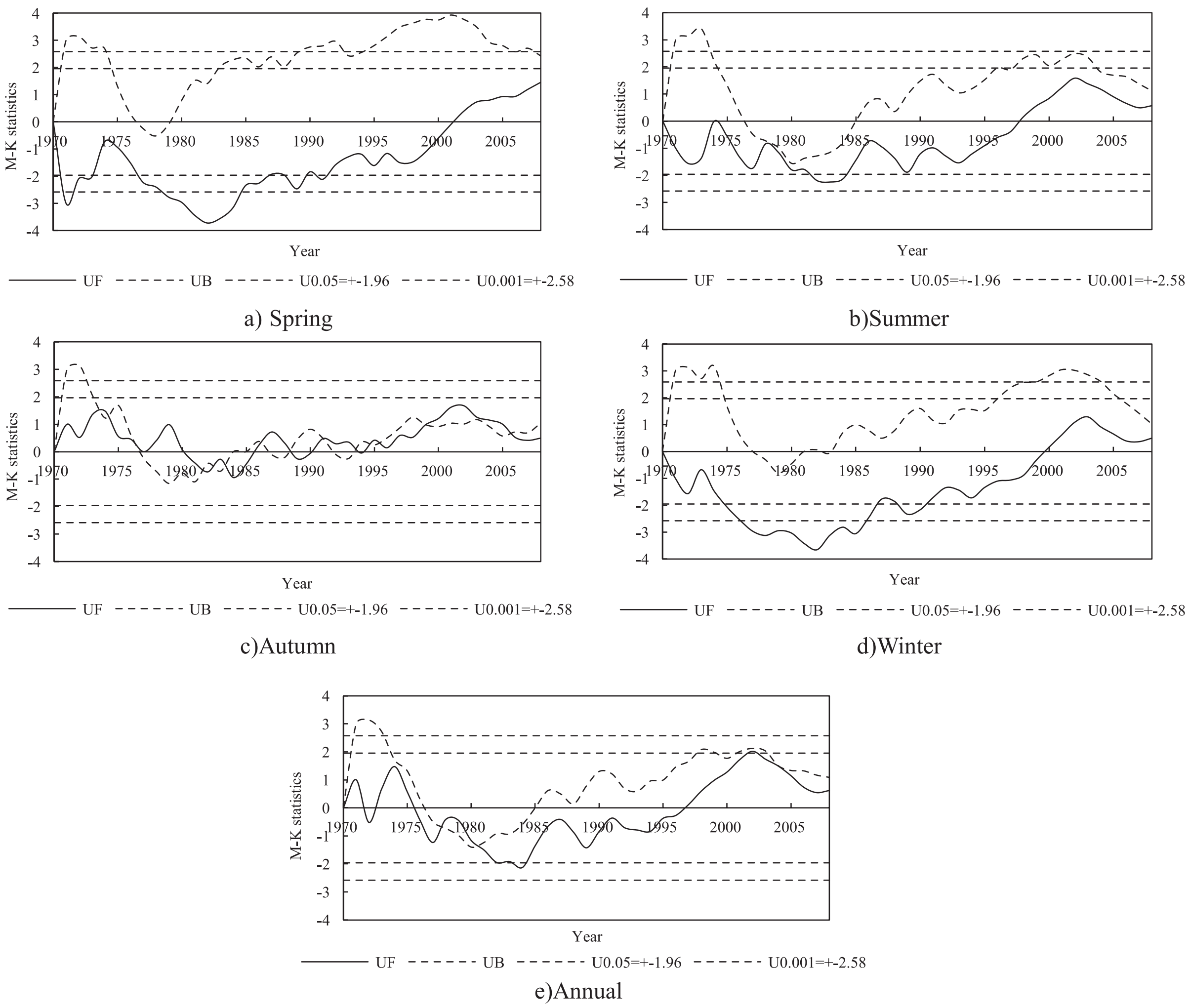


Fig. 2. Results of M-K mutation tests for runoff volume in different time scales in Longchuan River.

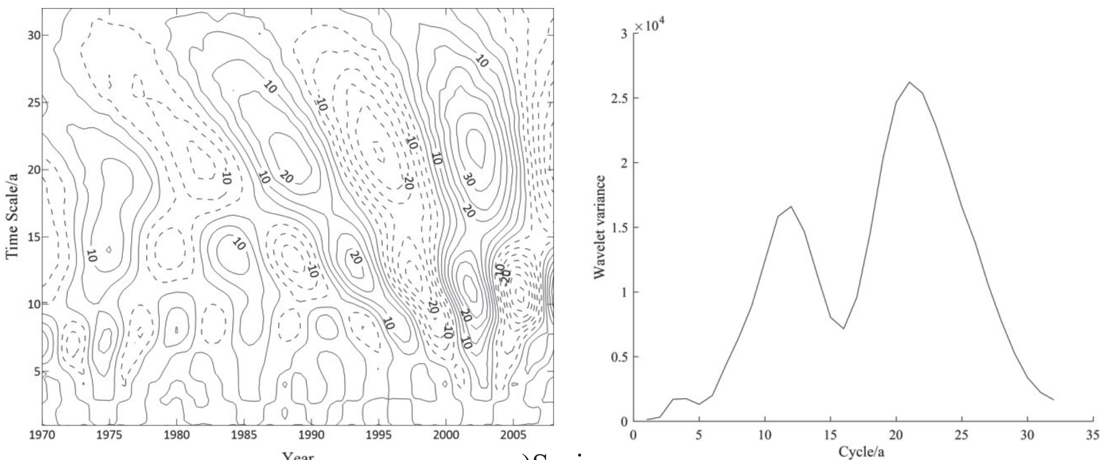
during 1970 to 1999 and an increasing trend during 2000 to 2008. Meanwhile, given that the |UF| values were greater than 1.96 during 1975 to 1986 and 1989 to 1990, it indicated that the winter runoff volume had a significant decreasing trend in this period. However, the UF and UB of winter runoff volume did not intersect during 1970-2008, which implied that no abrupt changes in winter runoff volume occurred (Fig. 2d).

Fig. 2e) showed that there were large fluctuations for annual runoff volume in different years among which the UF values of annual runoff volume were greater than 0 in 1970-1971, 1973-1975, and 1997-2008 when annual runoff volume had increasing trend, however the UF values turned to be less than 0 in 1972, 1976-1996 when annual runoff volume experienced increasing trends. Additionally, except for 1984 and 2002 when the value of |UF| was greater than 1.96, the values of |UF| were less than 1.96 in all other years, which revealed that the annual runoff volume had a significant decreasing trend in 1984 and a significant increasing trend in 2002, while the increasing or decreasing trends in other years were not significant. It also can be found from Fig. 2e) that the UF and UB of annual runoff volume intersected in 1978 and 1981, which indicated there existed an abrupt change for annual runoff volume in the Longchuan River during the two years.

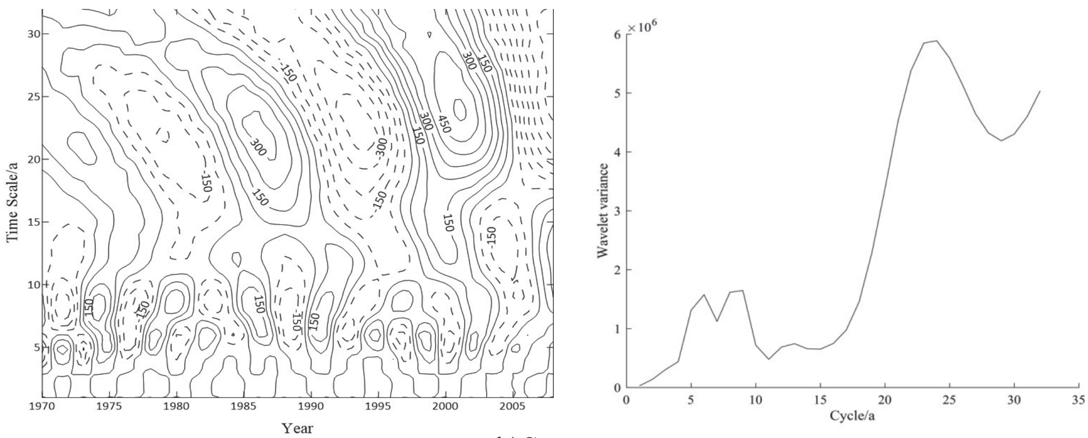
From the above analysis, it can be seen that the spring runoff volume generally showed a significant increasing trend at a rate of 0.649*10^6 m^3/a during 1970-2008, while the summer, autumn, winter and annual runoff volume were generally stable without significant change trend. In addition, the runoff volume in spring, summer, winter, and year experienced significant decreasing trends in some periods from 1970 to 2008, and the decreasing time was mainly concentrated from 1982 to 1984. Meanwhile, only autumn and annual runoff volume had abrupt change points between 1970 and 2008, while spring, summer and winter runoff volume did not have abrupt change points.

Periodic Variation of Runoff Volume

Wavelet analysis is an important tool that can be used to analyze periodicity characteristic of hydrological time series [27]. It can be found that there are multiple time scale characteristics for runoff volume in the four seasons and annual runoff volume (Fig. 3). There are three scales of periodical variation for runoff volume in both spring and winter, two scales of that

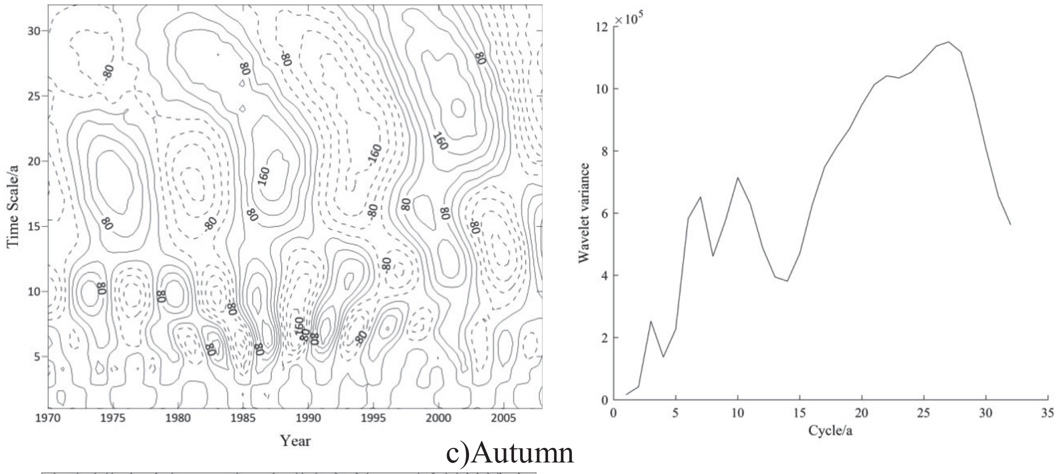


a)Spring

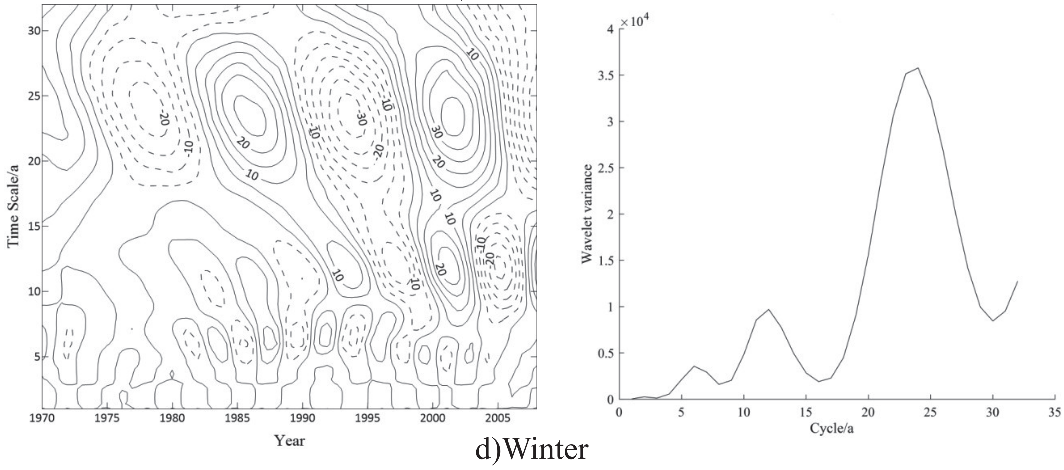


b)Summer

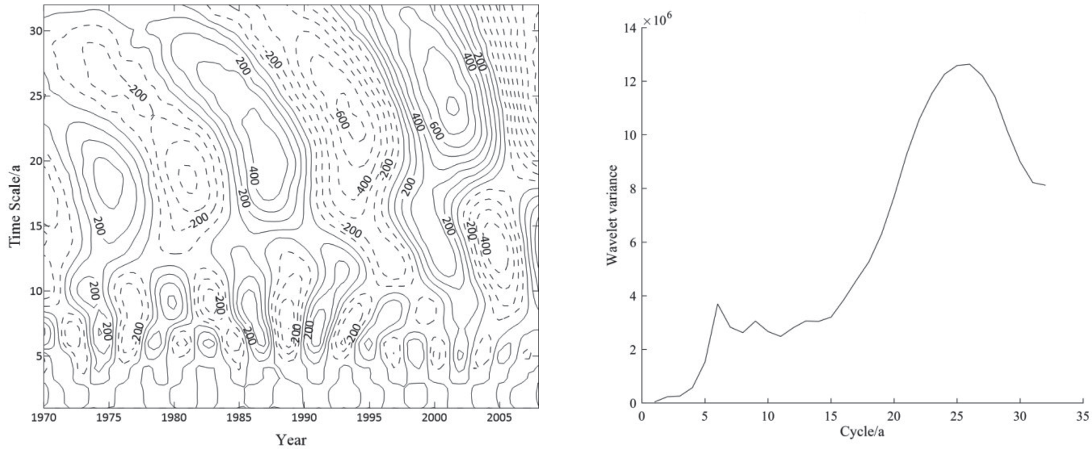
Fig. 3. Results of wavelet analysis for the four seasons and annual runoff volume in Longchuan River.



c)Autumn



d)Winter



e) Annual

Fig. 3. Continued.

for runoff volume in summer and annual runoff volume, and four scales of that in autumn runoff volume. In detail, the first principal cycles of spring and winter runoff volume were 21a and 24a, the second principal cycle was both 12a, and the third principal cycles were 4a and 6a, respectively; the first and second principal cycles of summer and annual runoff volume were both 26a and 6a, respectively; the first principal cycle of autumn runoff was 27a, and the second, third and fourth principal cycles were 10a, 7a and 3a, respectively. In summary, the seasonal and annual runoff volume in the Longchuan River fluctuated roughly with the first main cycle of 25a while varied with different minor cycles. In addition, the particular change process of runoff volume in the four seasons and annual runoff volume had some differences although they all had a first principal cycle of 25a or so. Specifically, the runoff volume of spring and winter were dominated by the conversion process of “abundance-depletion”, while those of summer and autumn as well as annual runoff volume were dominated by the conversion process of “depletion-abundance”.

Annual Variation of Sediment Transport Rate

The sediment transport rate reflects the amount of sediment transported by water under a certain condition of water flow and river bed, and is one of the important indicators of soil loss in a watershed. Fig. 4 reflected the overall change of sediment transport rate in the Longchuan River from 1970 to 2008, and it can be seen that the sediment transport rate is generally increasing at a rate of 4.29 kg/s/a (p = 0.02<0.05). To further explore the temporal variation pattern of sediment transport rate, the Mann-Kendall test was used to analyze the variations of sediment transport rate during 1970-2008.

Fig. 5 showed that the UF values of sediment transport rate were greater than 0 during 1970-2008. All these indicated that the sediment transport rate in the Longchuan River had a continuously increasing trend during this period. In addition, except for 1970-1972 and 1975 when the |UF| values were less than 1.96, all the UF values were greater than 1.96 in the other years, which demonstrated that the increasing trend of sediment transport rate was significant, especially changed to be extremely significant after 1985 (|UF|>2.58). Moreover, the UF and UB of sediment transport rate intersected in 2007 when the UF value was greater than 2.58, which indicated there existed an abrupt change for sediment transport rate in the Longchuan River from 1970 to 2008. However, it is noteworthy that the increasing trend of sediment transport rate before 1999 was very obvious, in contrast, it showed a certain decreasing trend between 2003 and 2008, which is possibly related to the national and local promotion of returning farmland to forest and grass in the new century.

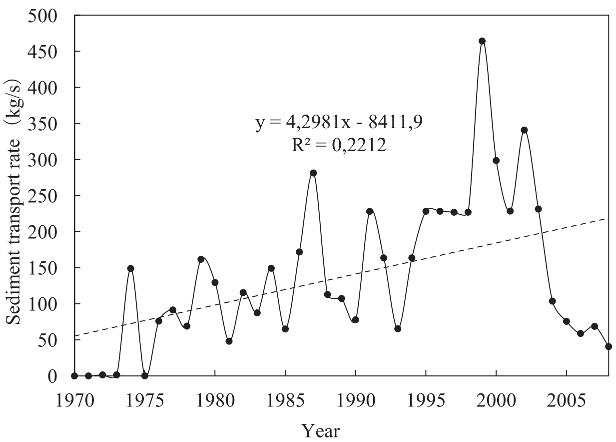


Fig. 4. Variation trend of sediment transport rate in Longchuan River.

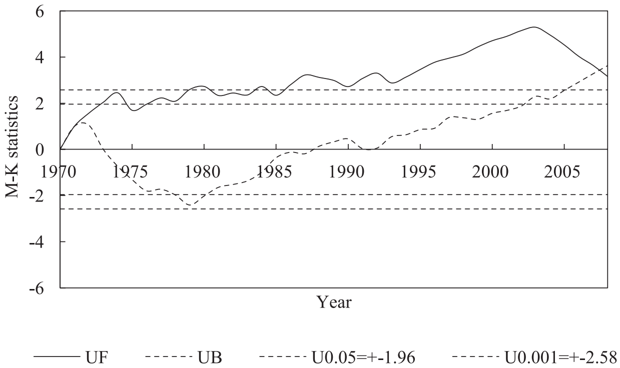


Fig. 5. Result of M-K mutation test of sediment transport rate in Longchuan River.

Periodic Variation of Sediment Transport Rate

It can be found from Fig. 6 that there were 2 scales of periodic changes for sediment transport rate in the Longchuan River from 1970 to 2008, which ranged from 4a to 7a and 14a to 32a, respectively. In detail, the first and second principal cycles of sediment transport rate were 29a and 6a, respectively. And the sediment transport rate was dominated by the conversion process of "drought-abundance" under the change of the first principle cycle; in contrast, the conversion process under the second principle cycle was not very obvious. Meanwhile, given that the real part of the wavelet was not closed in 2005, it suggested that the sediment transport rate would have a certain decreasing trend in the following years.

Relationship between Runoff Volume and Sediment Transport Rate

The relationship between runoff volume and sediment transport rate reflected the combination features of water flow and sediment yielding, which reflected not only the differentiation of flow and sediment production in the watershed, but also the bed-making effect on the river, and was one of the important parameters that analyze the change process of water and sediment. The regression analysis showed that there was a significant linear relationship between sediment transport rate and runoff volume in the Longchuan River (y = 44.627+0.116x, n = 39, R^2 = 0.216, p<0.01). It can be seen that the change of runoff would cause a significant change of sediment transport rate, but the contribution of runoff to sediment transport rate is only 11.6%, which indicated that there were still other factors affecting the change of sediment transport rate. To further probe the relationship between runoff and sediment transport rate in the Longchuan River, the synchronization of the two was analyzed in this study [26]. The results showed that the degree of synchronous difference η of runoff-sediment transport rate was generally greater than 1 during 1970 to 1990, and the value of η was greater than 30 in individual years. All these indicated that the relationship between water and sediment was extremely unbalanced before the 1990s. During 1991 to 2008, the index η of runoff-sediment transport rate was basically less than 1.

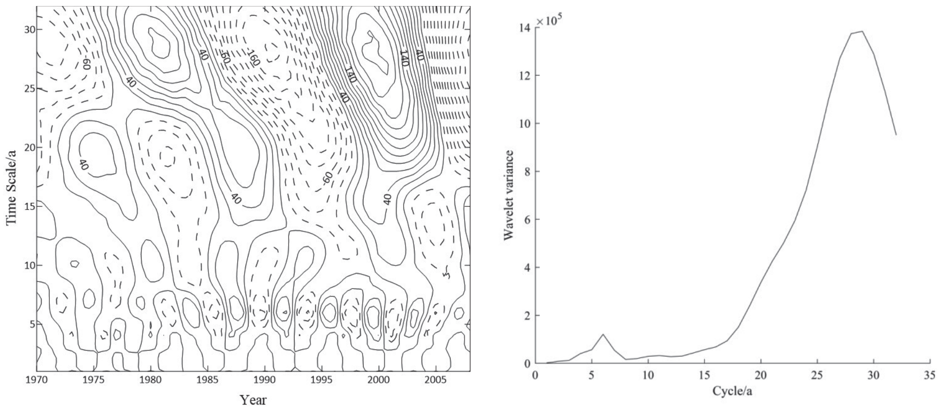


Fig. 6. Results of wavelet analysis for sediment transport rate in Longchuan River.

If the value of η in the year of 2005 and 2008 were not taken into account, the average η in the other 16 years was 0.469±0.431 during 1991 to 2008, which implied that the relationship between water and sediment was relatively balanced in this period.

The double accumulation curve was often used in hydrology to reflect the change features of water-sediment system in a basin. If the change trend of water-sediment system varied, the double accumulation curve would have an obvious turning point [28]. Fig. 7 showed that the double accumulation curve of runoff volume and sediment transport rate occurred deflection in 1974 and 2004. During 1970 to 1974, the cumulative curve of sediment transport rate was basically horizontal and approximate to 0 kg/s, which indicated that the sediment content was very low and just a little sediment had been transported into the Longchuan River. All these implied the good ecological environment and low intensity of agricultural development in the Longchuan River Basin in this period. From 1974 to 2003, the double accumulation curve turned to be a skew lines with an average gradient of 0.210, which mainly resulted from the increased development intensity of agricultural resource accompanied with the serious soil erosion caused by the destruction of forest and grassland. In 2004, the cumulative curve deflected again, and the gradient of the curve changed to be 0.115 from 2004 to 2008. The underlying reason was the vigorous promotion of returning farmland to forests and grasses and the strengthening of water conservation measures in the region since the beginning of the new century, thus reducing the sediment transport rate.

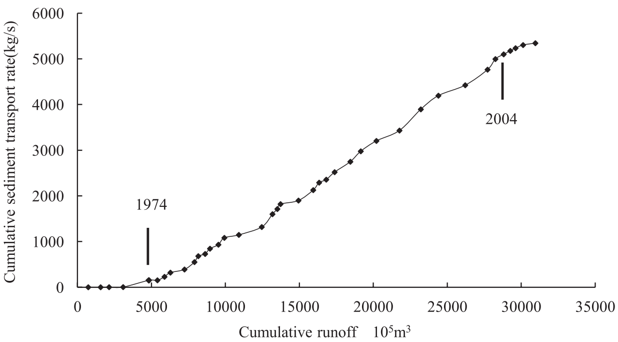


Fig. 7. Double accumulation curve of runoff volume and sediment transport rate in Longchuan River from 1970 to 2008.

Discussion

In this study, the variations of runoff volume and sediment transport rate as well as the relationship between runoff volume and sediment transport rate had been discussed. In general, the sediment transport rate experienced an increasing trend while runoff volume maintained in a relatively stable condition from 1970 to 2008. In contrast, Zhao et al. [13] found that both runoff and sediment discharge in the Yangtze River Basin decreased from 1953 to 2013. Shao et al. [29] mentioned that the runoff and sediment discharge of Jialing River have been greatly reduced due to climate change and the intensification of various human activities. All these indicated that the variation trends of runoff and sediment are different among different river basins due to different natural and human reasons. Meanwhile, given the individual change process features of runoff volume and sediment transport rate, the synchronicity of water-sediment relationship changed with the study period. All these founding implied that the influence of environmental change caused by climate and human activities on sediment transport rate is much greater than that on runoff volume, which demonstrated the sediment transport rate was a more sensitive environmental index than runoff volume. Therefore, sediment transport rate to some extent would be a priority indicator that can be used to predict the environment change. The synchronicity of runoff-sediment from 1970 to 1990 was very poor in which the degree of synchronous difference η between the two indictors was generally greater than 1 and even greater than 30 in individual years. The behind reason may be that the unordered development of water and soil resources had exacerbated erosion and sediment yield. On the other hand, the runoff volume was to some extent mainly affected by climate change which had not changed a lot before 1990, therefore the runoff volume remained stable. When time came to 1990s, water and soil conservation began to attract people's attention and the policy implementation of returning farmland to forest and grass in the new century reduced the sediment yield. At the same time, the ecosystem environment in the study area gradually improved which benefited from the implementation of soil and water conservation measures.

In addition, although the extremely positive relationship between runoff volume and sediment transport rate had been detected, the contribution rate of runoff volume to sediment transport rate was only 11.6%. This result indicated that sediment transport rate was affected directly by runoff volume, but there still were other factors influencing the sediment transport rate. And these other factors mainly included the environmental factors and human factors. According to the previous researches, climate change and human activities were the main two factors. Precipitation and temperature are two important indexes reflecting climate change [2, 30]. Precipitation and temperature will affect the water cycle in a basin, and surface runoff caused by precipitation is an important driving force of soil erosion [31]. Çakmak et al. [32] found that the amount and rate of suspended sediment increased significantly during the shorter flood period in summer months (e.g., May and June) due to short-term heavy precipitation in the Korkuteli Stream in the Mediterranean region of Turkey. Li et al. [33] deemed that the most important factors that influencing the annual runoff and sediment yield were heavy precipitation amount, and the extreme precipitation was the key factor for runoff generation in karst watersheds, and also had a significant impact on sediment yield in the basin. As to the influence of temperature, both Kun [31] and Panondi [34] found that increasing temperature would reduce runoff yield while the rate of reduction slowed with increasing temperature variability, at the same time, the increase of temperature can cause an increase in sediment production.

In addition, many previous studies had shown that human activities played a leading role in the change of water and sediment in a basin [3, 8, 35-37]. Many scholars deemed that human activities such as soil and water conservation, damming and land using change, and water diversion and sand mining had a strong direct and indirect impact on global river systems especially on sediment content in a river [1, 8, 10, 32, 34, 38-41]. For example, Restrepo et al. [42] found that the dramatic increase in sediment load in major watersheds in the Colombian Andes was due to extensive human deforestation, and forest cover decreased by 40% from 1980 to 2010, while the area under agriculture and pasture cover increased by 65%. In addition, Xue et al. [43] concluded that the contribution of human activities to runoff reduction was 88.72% in the Shiyang River Basin from 1960 to 2018, and human activities played the most dominant role in the variation of runoff.

All the above-mentioned demonstrated that climate change and human activities can changed the runoff and sediment yield in a basin so as to influence the relationship between runoff and sediment. As a consequence, exploring the specific influence of climate change and human activities on runoff and sediment was very necessary, especially in Longchuan River where few relative studies had been conducted. However, previous studies about this theme were mainly concentrated in Yellow River [1], Yangtze River [8], Mekong River [44], and other main rivers in the world [3, 30, 45, 46]. Therefore, explore the influence of climate change and human activities specifically and deeply on runoff and sediment would be our further key task.

Conclusions

This study probed the variations and relationships between runoff volume and sediment transport rate in Longchuan River from 1970 to 2008. The results showed that runoff volume mainly was stable, and sediment transport rate experienced a significant increasing trend at a rate of 4.29 kg/s/a. Except for the general variation trend, the change cycles of runoff volume and sediment transport rate were also obviously different. Among which, the first principal cycles of seasonal and annual runoff volume were all 25a, while the second and third principal cycles were different. In contrast, the first and second principal cycles of sediment transport rate were respectively 29a and 6a. There was a significant linear relationship between sediment transport rate and runoff volume in Longchuan River ($y = 44.627 + 0.116x$, $n = 39$, $R^2 = 0.216$, $p<0.01$), i.e., the sediment transport rate increased with the increase of runoff. Moreover, the relationship between runoff volume and sediment transport rate is different in different periods. The synchronicity of water-sediment relationship was poor in 1970-1990, while that turned to be good in 1991-2008. 1974 and 2004 were the years that waster-sediment relationship changed in Longchuan River.

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Conflicts of Interest

The authors declare no conflict of interest.

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