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Research Article

Prediction of Runoff Change considering the Influences of Reservoir Group

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2. Keywords

Reservoir group; Trend rate method; Sliding T test; Mutation analysis; Cycle analysis

1. Abstract

In order to explore the influence of the construction of reservoir group in the upper reaches of the Minjiang River basin on the hydrological evolution of the basin. The trend, mutagenicity and cyclicality of runoff changes in the Minjiang River basin from 1950 to 2015 were analyzed by means of trend rate method, sliding T test, Mann-Kendall test, wavelet analysis and other statistical methods. The results show that the annual changes of runoff and flood season in the basin show a decreasing trend, and non-flood season runoff shows an increasing trend. The results of mutation test and hydrological index change analysis show that the construction and operation of the Minjiang Reservoir Group is the main reason for the mutation of runoff changes. Among them, during the operation of Gongzui Reservoir, the overall change of 13.7 % was a low change; After the joint operation of Gongzui Reservoir and Tongjiezi Reservoir, the overall change was 34.3 %, which was a moderate change; The overall variability of the runoff of the high field station during the four-library parallel operation was 38.2%, which was a moderate change. From the results of cyclic analysis, it can be seen that the cyclical changes in the process of runoff evolution in the Minjiang River basin are the most obvious, while the cyclical changes in other time scales are relatively small. Among them, the 19-year time scale is the maximum peak, indicating that the cycle of about 19 years is the strongest, and it is the first main cycle of annual runoff changes; The seven-year time scale corresponds to the second peak, and the runoff change is the second main cycle.

3. Introduction

Minjiang River is one of the important branches at the upstream of Yangtze River. Started from the south of Minshan Mountain, it flows by the west of Sichuan Basin from the northwest to the southeast and finally flows into Yangtze River at Hejiangmen, Yibin City. As to geographical location, Minjiang River locates between 102°35′ ~103°57′ E and 30°40′ ~33°10′ N, having a total length of main stream in 1,279km, drainage area of 135,400km2 and natural head of about 3,650m. Gaochang Hydrological Station is the outlet control station of Minjiang River Basin with annual average runoff volume of 84,600,000,000m^3. Most of the Minjiang River Basin belongs to subtropical climate and the upstream section is mainly in mountain topography, belonging to mountain and plateau climate. The rainfall of Minjiang River Basin is mainly controlled by southeast and southwest monsoon. Its rainfall changes with the season obviously, centering on June to September, and the rainfall volume in summer and autumn takes up over 80% of the whole year. Topography has a great influence on the rainfall volume of different regions. From Song pan County to Wenchuan County, its annual mean precipitation is 400~700mm; from Yingxiuwan of Wenchuan County down to Dujiangyan City, it is the rainfall center of the main stream of Minjiang River and its annual mean precipitation is 1,100~1,600mm.

Climate change leads to the changes of rainfall, evaporation, runoff, etc., leads to redistribution of water resources in time and space and the changes of total amount of water resources and increases the probability and strength of extreme disasters as well, which has a huge impact on the sustainable development of ecological

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Table 1: Basic Parameters of the Big II Reservoirs and Above Within the Study Area

Belonged to	Reservoir	Control Station	Total Capacity (hundred million m^3)	Started Operating and Completed in
Dadu River	Gongzui	Gaochang Station	3.1	The first unit started operating in 1972, completed in 1978
	Tongjiezi		2	The first unit started operating in 1992, completed in 1994
	Pubugou		53.9	2009
Minjiang River	Zipingpu		11.2	Started water storage in 2006

Table 2: Table for Runoff Change Trend at Gaochang Station

Month	January	February	March	April	May	June	July
Trend	1.00	3.42	3.96	2.52	-5.61	-6.61	-23.14
Month	August	September	October	November	December	Flood season	Non-flood season
Trend	-19.75	-20.52	-13.54	-5.22	2.17	-15.75	0.67

environment and social economy [1]. In recent decades, lots of researches about the impacts of climate changes on hydrology and water resources have been made at home and abroad and achieved fruitful results [2] researched and found that different regional climate changes have different impacts on the runoff volume [3] applied TFPW-MK test to have analyzed the correlation between meteorological elements and runoff series of Liard River.

Besides the above impacts on runoff changes made by climate change, human activities also influence the hydrologic cycle of basin. It is a hotspot and frontier issue of global change studies on human activities change land use (construction of reservoir group) and vegetation cover leads to the changes of hydrological process [4] applied IHA method in the research on runoff changes of Huaihe River Basin, finding that hydraulic engineering has a great impact on the runoff volume in dry season; [5] used the rainfall data of the upstream of Yangtze River to simulate the runoff changes of Yichang and compared ecological indexes with IHA factors; [6] figured out that more control reservoirs on the mainstream of the Yellow River result in higher change of hydrological regime; [7] adopted IHA method to have analyzed the impacts on hydrological regime made by the reservoir group at the upstream of Yangtze River; [8] used RVA method to have evaluated the impacts on downstream

Table 3: Runoff Mutation Analysis

Station	Possible Mutation Year		
	M-K Mutation Test	n=5, Sliding T Test	n=10, Sliding T Test
Gaochang Station	1973, 1993	1968, 1973, 1993	1968

hydrological regime made by the Three Gorges Reservoir, finding that impact of reservoir operation on downstream weakens along the river; [9] made attribution analysis on the factors that change runoff volume, finding that rainfall reduction in flood season is the main cause of runoff volume decrease. However, [10] thought that RVA method hadn't considered the annual change of runoff characteristics and ignored its impact.

4. Study Area and Data

4.1. Reservoir Selection

In view of the geographical location of Gaochang Station, runoff changes of the Station can reflect incidence of the regulation and storage of the reservoir group on Minjiang River and Dadu River. As it is difficult to collect the data related to storage and discharge of reservoirs, only the Big II reservoirs and above on Minjiang River and Dadu River are taken into consideration. Basic parameters of the reservoirs can see (Table 3).

4.2. Data

With the runoff changes at the outlet control hydrological station of Minjiang River Basin - Gaochang Station as the object of study and with the measured runoff data in monthly scale at Gaochang Station from 1950 to 2015 (66 years in total) as the basis of analysis, this paper mainly studies the change laws that the completion and operation of reservoirs made on the runoff factors of basin through using the completion and operation time of Gongzui Reservoir, Tongjiezi Reservoir and Zipingpu Reservoir to divide the time nodes under the impact of reservoirs respectively.

5. Main Study Methods

5.1.Trend Rate Method

Generally speaking, the trend change of time series can be described with a linear equation or quadratic curve equation. Here, a linear equation is applied. Suppose the time series of temperature at a station to be $x_1, x_2, \ldots, x_n$, and the simple linear regression equation between x_i and t can be expressed as:

Table 4: Runoff Volume of Gaochang Station under Natural State

Index		1	2	3	4	5	6	7	8	9	10	11	12	Max	Min
Mean m/s		780	725	856	1236	2216	4104	6895	6336	5047	3461	1894	1114	7447	715
RVA threshold	Upper limit m^3/s	720	657	721	923	1760	3333	5089	4596	3767	2844	1673	1005	5778	650
	Lower limit m^3/s	841	793	991	1548	2673	4875	8702	8076	6326	4079	2116	1222	9116	779

Table 5: Hydrological Index Change Degree after Reservoir Construction

Station	Index	One-reservoir Operation of Gongzui Reservoir					Two-reservoir Operation of Gongzui and Tongjiezi Reservoirs					Four-reservoir Operation of Pubugou and Zipingpu Reservoirs				
		Mean m^3/s	Change Rate %	Degree	Weight %	Overall Change Rate %	Mean m^3/s	Change Rate %	Degree	Weight %	Overall Change Rate %	Mean m^3/s	Change Rate %	Degree	Weight %	Overall Change Rate %
Gaochang Station	Jan	774	7.1	Low	0.9	13.7	799	15.6	Low	1	34.3	1169	100	High	2.8	38.2
	Feb	711	12.3	Low	0.8		756	15	Low	1.3		1101	69.3	High	2.7	
	Mar	827	16.4	Low	1.7		886	27.3	Low	2.5		1292	66.3	Moderate	3.4	
	Apr	1288	5.9	Low	5.4		1283	46.6	Moderate	3.4		1414	58.8	Moderate	1.9	
	May	2124	5.9	Low	6.3		2114	34.4	Moderate	4.6		1708	19.1	Low	5.9	
	Jun	4096	13.4	Low	13.2		4014	2.3	Low	10.3		3303	19.1	Low	6.3	
	Jul	6200	11	Low	12.9		5081	33.9	Moderate	17.6		5891	8	Low	22	
	Aug	5665	28.6	Low	14.9		5277	58.8	Moderate	18.2		4747	19.1	Low	12.8	
	Sept	5187	21	Low	18.7		4199	22.2	Low	15.8		3702	58.8	Moderate	13.1	
	Oct	3276	3.6	Low	10		2762	27.3	Low	5.9		2718	32.5	Low	6.6	
	Nov	1809	12	Low	3.2		1653	34.4	Moderate	2.8		1535	64.5	Moderate	0.9	
	Dec	1151	14.3	Low	1.3		1090	26.9	Low	1.1		1354	100	High	1	
	Max	6545	2	Low	9.8		5718	43.8	Moderate	14.3		5672	57.1	Moderate	18.5	
	Min	723	10	Low	0.8		738	40.9	Moderate	1.3		1048	77.5	High	2.3	

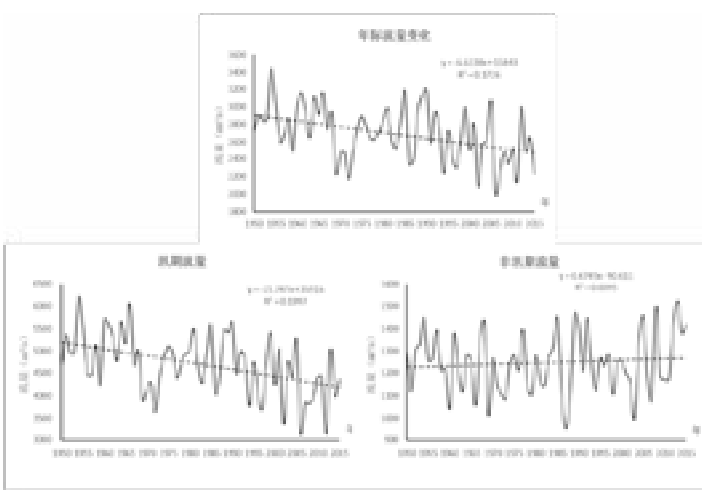
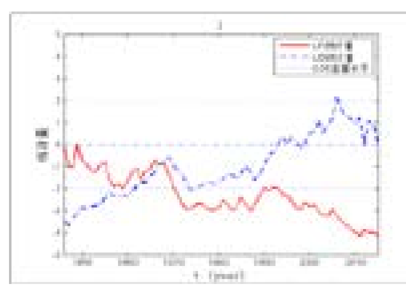


Figure 1: Runoff Change Trend at Gaochang Station

$$y_i = a + bt_i, \quad i = 1,2,\ldots,n \qquad (1)$$

In the above equation, a represents intercept and b represents regression coefficient. Least square method can be applied to obtain a and b. As trend rate of time series change, regression coefficient b can reflect the change rate of time series.

年际流量变化	Annual flow change
汛期流量	Flow rate in flood season
非汛期流量	Flow rate in non-flood season



UF' ' '	UF Statistic
UB' ' '	UB Statistic
0.05' ' ' '	0.05 Significance Level
' ' '	Statistic

Figure 2 (a) M-K Mutation Test Pattern

5.2. Sliding T Mutation Test

When difference between the means before and after series exceeds

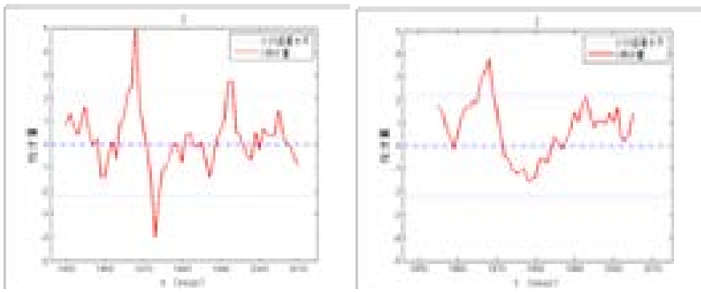


Figure 2(a): Results of Runoff Series Mutation Test

0.05显著水平	0.05 Significance Level
t统计量	t Statistic
统计量	Statistic

(b) 滑动T检验n=5 （c）滑动T检验n=10

(b) Sliding T Test, n=5 (c) Sliding T Test, n=10

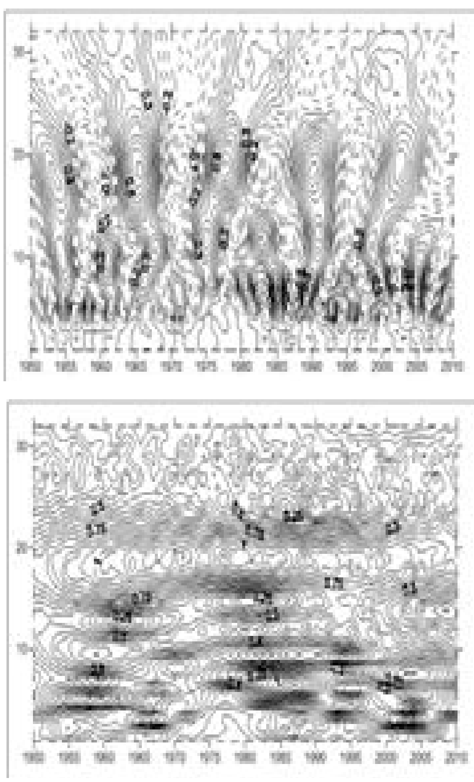


Figure 2(b): Real-part Contour Map for Runoff Wavelet Coefficient at Gaochang Station (Left), Contour Map for Wavelet Coefficient Module (Right)

certain significance level, it is considered to have mutation. Setting a certain point of time as mutation node, the series x composed of n samples are divided into two subseries x_1 and x_2 before and after the mutation node, samples are divided into n_1 and n_2, corresponding to serial means $\overline{x_1}$ and $\overline{x_2}$, variances S_1^2 and S_2^2. Then, statistic can be defined as:

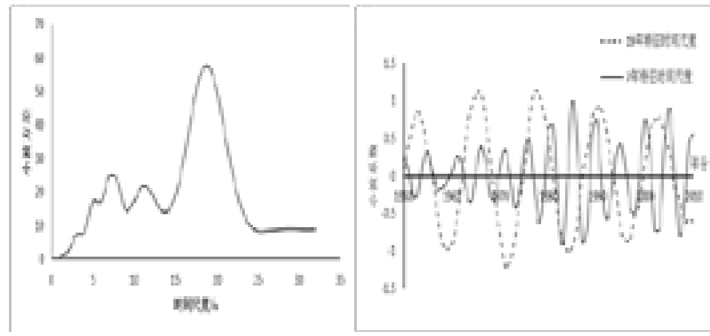


Figure 3: Wavelet Variogram (Left), Wavelet Real-part Hygrograph in 19-year & 7-year Time Scale of Runoff Changes (Right)

小波方差	Wavelet variance
时间尺度	Time scale
小波系数	Wavelet coefficient
年份	Year
19年特征时间尺度	19-year time scale
7年特征时间尺度	7-year time scale

$$t = \frac{\overline{x_1} - \overline{x_2}}{S_w \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (2)$$

$$S_w = \sqrt{\frac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - 2}} \quad (3)$$

Sliding method is applied to set mutation node continuously, and statistic t can be calculated respectively to acquire statistical series $t_i, i = 1,2,\ldots n-(n_1+n_2)+1$. Then, check t_α at Statistical Distribution Table: $|t_i| > t_\alpha$, mutation time point is the datum point.

5.3 M-K Trend Analysis

M-K test is a nonparametric test method recommended by the WMO to widely apply. It doesn't require the samples to obey certain distribution laws, nor interfered by abnormal values, and it is applicable for the ordinal variables of meteorology, hydrology, etc.

M-K trend analysis process: suppose sample data $(x_1, x_2, \ldots, x_n)$ to be independent with random variables identically distributed, and distribution of x_i is different from that of $x_j\ (x_i, x_j, i, j \leq n \text{ and } j > i)$

. When $n > 10$, statistical variable S of trend test is calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i) \quad (4)$$

$$Sgn(x_j - x_i) = \begin{cases} +1 & (x_j - x_i) > 0 \\ 0 & (x_j - x_i) = 0 \\ -1 & (x_j - x_i) < 0 \end{cases} \quad (5)$$

In the above equations: S represents the normal distribution when mean value is 0, and variance is $\mathrm{var}(S) = [n(n-1)(2n+5)]/18$. When $n > 10$, standard normal statistical variable Z can be expressed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{var}(S)}} & S < 0 \end{cases} \quad (6)$$

$Z_{1-\alpha/2}$

is the $1-\alpha/2$ quantile under standard normal distribution. Suppose the series to have no trend changes at the beginning, bilateral trend test is applied and significance level α is given. If $|Z| \geq Z_{1-\alpha/2}$, the original supposition is invalid and it is considered that the series under significance level α has obvious change trend; if $|Z| < Z_{1-\alpha/2}$, the original supposition is valid and it is considered that the change trend is not obvious. When $Z > 0$, sample series shows a trend of increase in general; when $Z < 0$, sample series shows a trend of decrease in general.

5.4 M-K Mutation Test

Time series is $t_1, t_2, \ldots t_n$, structural series is r_i, and r_i represents the sample count when $t_i > t_j (1 \leq j \leq i)$. Then, S_k can be defined as:

$$S_k = \sum_{i=1}^{k} r_i \quad (k = 2,3, \ldots \quad (7)$$

$$\begin{cases} r_i = +1, & x_i > x_j \ (j = 1,2, \ldots, \\ r_i = 0, & \text{or else} \end{cases} \quad (8)$$

Mean value $E(S_k)$ and variance $\mathrm{var}(S_k)$ of S_k are defined as:

$$E(S_k) = \frac{n(n+1)}{4} \quad (9)$$

$$\mathrm{var}(S_k) = \frac{n(n-1)(2n+5)}{72} \quad (10)$$

Suppose the series to be random and independent, and then the statistic UF_k can be defined as:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{\mathrm{var}(S_k)}} \quad (k = 1,2, \ldots,) \quad (11)$$

In the above equation, UF_k is standard normal distribution and $UF_1 = 0$.

Check the table for significance level α to obtain critical value U_α. When $|UF_k| > U_\alpha$, it indicates that the series has obvious trend of increase or decrease. Connect all UF_k to draw a curve c_1 and change the original series to its antitone; then multiply its calculated value by -1 and repeat the above process to obtain UB_k, and connect all UB_k to draw curve c_2. Draw curves UF_k and UB_k respectively, and if the intersection of curves c_1 and c_2 locates between credibility lines, it indicates that this point is the point of mutation.

5.5 Hydrological Index Change Degree

Hydrological index change degree is defined as:

$$D_i = \left| \frac{N_i - N_e}{N_e} \right| \times 100\% \quad (12)$$

In the above equation, D_i represents change degree of the i index; N_i represents the number of years still included in RVA target scope after mutation of the i index; N_e represents the number of years predicted to be included in RVA target scope after mutation, which can be obtained by means of multiplying the proportion in target scope before mutation by the number of years after mutation. When D_i is lower than 33%, hydrological index is considered to have a low change; when D_i is 33%~67%, it is considered to have a moderate change; when D_i is 67%~100%, it is considered to have a high change.

5.6 MorletWavelet Cycle Analysis

If different wavelet base functions are selected for the same time series or signal, the results acquired are also different. At present, required wavelet base function is selected through comparing the analytical and processing result error of different wavelets. When Morlet wavelet is selected as mother wavelet for transform, Morlet wavelet function is defined as:

$$\psi(t) = \pi^{-1/4} e^{-iw_0 t} e^{-t^2/2} \qquad (13)$$

In the above equation, w0 is a constant (generally w>=5); i is imaginary number. Arbitrary function $f(x)$ can be defined as follows in wavelet transform:

$$W_f(a,b) = \int_{\infty} f(x)\overline{\psi(a,b)}(x)dx = |a|^{-\frac{1}{2}} \int_{\infty} f(x)\bar{\psi}(\frac{x-b}{a})\, dx \qquad (14)$$

In the above equation, $W_f(a,b)$ is wavelet coefficient and its discrete transformation can be described as Equation (3-16); $\psi(x)$ and $\bar{\psi}(x)$ are complex conjugate functions;

$$W_f(a,b) = |a|^{-\frac{1}{2}} \Delta t \sum_{k=1}^{n} f(k\Delta t)\bar{\psi}(\frac{k\Delta t - b}{a}) \qquad (15)$$

In the above equation, $f(k\Delta t)$ can be outputted by 3D pulse filter, and its value can reflect the characteristics of both time domain parameter b and frequency domain parameter a.

Draw a 2D contour map of $W(a,b)$, which can reflect wavelet transform characteristics of the series. In the map, the real part shows signal distribution at different time and the size of module shows signal strength.

Integrate the squared value of wavelet coefficient on Domain b to obtain wavelet variance:

$$Var(a) = \int_{-\infty}^{\infty} |W_t(a,b)|^2 \, db \qquad (16)$$

Wavelet variogram shows the value of wavelet variance changes with Scale a. The map can reflect the condition that signal energy distributes with Scale a, and it can be used to determine corresponding strength and the main time scales when signal disturbance occurs.

6. Case Application and Result Analysis

6.1 Analysis on Runoff Trend

Annual average flow of Gaochang Hydrological Station is 2,700m^3/s. Upon significance test, both annual runoff and flood season tend to decrease, and annual runoff in non-flood season tends to increase (Figure 1). Among them, annual runoff decreases in a rate of 2.09×109m^3/10a; runoff decrease trend in flood season is the most obvious in a change rate of 4.96×109m^3/10a; runoff tends to increase in non-flood season in a change rate of 2.13×108m^3/10a. Runoff trend analysis is made on the measured runoff data of Gaochang Hydrological Station month by month. As shown in (Table 2), runoff volume tends to increase from January to April and in December, and it tends to decrease from May to November. The reason is: with the construction and operation of reservoir group on the Minjiang River, reservoirs store water and raise water level gradually in the flood season from May to November to control flood and meet the demand of hydroelectric generation, so as to calm inflow peak and decrease natural runoff volume at the downstream of reservoirs in flood season; in non-flood season, in order to meet the demands of shipping, ecological water supply and power generation, etc., reservoirs release water to reduce storage, so as to make the runoff volume increase compared with natural runoff. Generally speaking, influenced by climate change and human activities, runoff volume at the Minjiang River Basin tends to decrease.

6.2 Runoff Mutation Analysis

RVA method is proposed on the basis of IHA index to analyze the incidence on runoff hydrological situation made by the construction and operation of hydraulic engineering[11]. Runoff series at Gaochang Station needs to be divided into natural state and affected state with this method. In order to avoid the mutation point in mutation statistical analysis from lacking of physical interpretation or the wrong conclusions caused by improper use of mutation test method, M-K method and sliding T test are applied for comparative analysis, and strict significance level is given for test. With mutation test on the annual runoff series of Gaochang Hydrological Station, results of the mutation point in runoff series are obtained as shown in (Table 4). Time dividing point of runoff mutation can be identified by considering the mutation results obtained by the two tests and the operation start time of large reservoirs. According to the runoff time series at Gaochang Station, with 25% of the probability of the 14 indexes, including annual flow from January to December, annual maximum flow and annual minimum flow as the lower limit of RVA target and with 75% of the probability as upper limit of RVA target, index change of Gaochang Station under the joint operation model of reservoirs is analyzed, and the results are shown in (Table 5 and 6).

From 1973 to 2009, monthly average flow at Gaochang Station was mainly impacted by the construction and operation of Daduhe Reservoir, and it increases with the construction of cascade reservoirs. Among them, during the operation of Gongzui Reservoir, the overall change rate was 13.7%, which was regarded as a low change; after the joint operation of Gongzui Reservoir and Tongjiezi Reservoir, the overall change rate became 34.3%, which was regarded as a moderate change. This indicates that impact on the runoff of downstream control stations in pre-flood season and flood season caused for cascade reservoirs on Dadu River store water during regulation and storage cycle increases. From 2010 to 2015, Pubugou Reservoir was built on the Dadu River and Zipingpu Reservoir was built on the Minjiang River, which constituted a joint operation model, resulting in that the non-flood season runoff volume of Gaochang Station shows a moderate change and the change of flood season runoff volume is reduced to moderate. Generally speaking, the overall change rate of the runoffs at Gaochang Station under the joint operation of four reservoirs was 38.2 %, which was regarded as a moderate change.

6.3 Cycle Analysis

In the following (Figure 2 and 3), it shows four maps related to the results of annual runoff wavelet analysis of Gaochang Hydrological Station, including Real-part Contour Map for Wavelet Transform, Module Contour Map, Wavelet Variogram and Main Cycle Wavelet Coefficient Map.

Real-part Contour Map (Figure 2 (Left)) can clearly present that the runoff evolution is characterized in multiple time scales. The entire runoff evolution process of Gaochang Station can be divided into three time scales, including 3~9 years, 10~25 years and 25~32 years. Among them, dry-wet alternation occurred for five times on 10~25-year time scale; besides, it can figure out that cycle changes on the 3~9-year time scale and 10~25-year time scale are very stable throughout the entire time period being analyzed.

Morlet wavelet coefficient module can reflect the conditions about the energy density of different time scale cycles distributed in time domain, and the value of energy density is bigger, cyclicity of corresponding time scale is stronger. It can be seen from (Figure 2) that during the runoff evolution process of the Minjiang River Basin, cycle change of 10~25-year time scale is the most obvious and the cycle changes of other time scales are relatively small. Wavelet Variogram can identify the wave energy of runoff series and the main cycles existed in evolution process intuitively. In (Figure 3 (Left)), it has five obvious peaks, corresponding to the time scales of 3, 5, 7, 12 and 19 years. Among them, 19-year time scale is the maximum peak, indicating that the cycle of about 19 years is the strongest and it is the first main cycle of annual runoff change; the 7-year time scale corresponds to the second peak and it is the second main cycle of annual runoff change; the third, fourth and fifth peaks correspond to 12-year, 5-year and 3-year time scales respectively. Waves of the five cycles control change characteristics of runoffs in the entire basin.

Draw wavelet coefficient maps for the first and second main cycles (Figure 3 (Right)) and it can figure out that on the 19-year time scale, average cycle of runoff changes of the Minjiang River Basin is 12 years and it has gone through wet-dry alternation for about five times; on the 7-year time scale, average cycle of runoff changes is 5 years and it has gone through wet-dry alternation for about twelve times.

7. Conclusions

Make analysis on the tendency, mutation and cyclicity according to the monthly measured runoff data of Gaochang Hydrological Station from 1950 to 2015, divide runoffs into natural state and affected state according to mutation node and use hydrological regime analysis method to make quantitative analysis on the runoff change degree. And it reaches the following conclusions:

(1) At Gaochang Hydrological Station, both annual runoff and flood season tend to decrease, and annual runoff tends to increase in non-flood season. Among them, annual runoff decreases in a rate of $2.09\times109m^3/10a$; runoff decrease trend in flood season is the most obvious in a change rate of $4.96\times109m^3/10a$; runoff tends to increase in non-flood season in a change rate of $2.13\times108m^3/10a$. The reason is: with the construction and operation of reservoir group on the Minjiang River, reservoirs store water and raise water level gradually in the flood season from May to November to control flood and meet the demand of hydroelectric generation, so as to calm inflow peak and decrease natural runoff volume at the downstream of reservoirs in flood season; in non-flood season, in order to meet the demands of shipping, ecological water supply and power generation, etc., reservoirs release water to reduce storage, so as to make the runoff volume increase compared with natural runoff. Generally speaking, influenced by climate change and human activities, runoff volume at the Minjiang River Basin tends to decrease.

(2) At Gaochang Station, monthly average flow increases with the construction of cascade reservoirs. Among them, during the operation of Gongzui Reservoir, flow changes from January to December are all regarded as low; after the joint operation of Gongzui Reservoir and Tongjiezi Reservoir, the overall change is regarded as moderate. This indicates that impact on the runoff of downstream control stations in pre-flood season and flood season caused for cascade reservoirs on Dadu River store water during regulation and storage cycle increases. From 2010 to 2015, Pubugou Reservoir was built on the Dadu River and Zipingpu Reservoir was built on the Minjiang River, which constituted a joint operation model, resulting in that the non-flood season runoff volume of Gaochang Station shows a moderate change and the change of flood season runoff volume is reduced to moderate. Affected by joint operation of reservoirs, overall change rate under the hydraulic elements of channels is 38.2%, being regarded as moderate change.

(3) Runoffs at the Minjiang River Basin have five obvious cycles, corresponding to the time scales of 3, 5, 7, 12 and 19 years. Among them, 19-year time scale is the first main cycle of annual runoff change and the first main cycle of runoff evolution has gone through wet-dry alteration for about five times.

Reference

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