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To cite this article: Kong Chunmei *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **267** 032079

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Multi-scale characteristics analysis of annual inflow runoff of Nanma reservoir

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Abstract: The inflow runoff of reservoir plays a vital role on the reservoir optimization regulation and flood control. Based on the inflow runoff series of Nanma reservoir for the period of 1960-2004, the annual and inter-annual characteristic of runoff series were analyzed. After decomposed by the approach of Empirical Mode Decomposition, the multi-scale characteristic of annual inflow runoff was analyzed by the methods of Hilbert-Huang transform, Mann-Kendall and Rescaled Range Analysis. The results showed that, for the past 45 years the average monthly runoff of Nanma reservoir presented single peak distribution. The precipitation of flood season was the main source for annual inflow runoff. The multi-scale characteristic of annual inflow runoff was obviously and presented various periods of 2.4a, 3a, 6a and 12a. The mutation time of annual runoff was 1961, and the runoff would continue to have a increase trend in the future.¹

1.Introduction

The hydrological system is an open and complex giant system. Among them, river runoff is affected by natural factors and human activities, and the multi-time scale characteristics are obvious [1]. As a kind of building that intercepts floods and regulates rivers to achieve reasonable supply and demand of water resources, the reservoir plays an irreplaceable role in joint reservoir dispatching, residential water use, agricultural irrigation water and industrial water use [2-3]. Nanma Reservoir is located in Jingnan Town, Luanchuan County, Yunnan Province, and is located on the Nanma River, a tributary of the left bank of the Nanwan River in the town. The Luanchuanba area where Jingnan Town is located has a subtropical monsoon climate. The annual average temperature is 18.9 °C, the annual rainfall is 1544 mm, the Nanma River Basin is 24.1 km², and the average annual water resources is about 18.39 million m³. Considering that the main water supply of the Nanma Reservoir is to use water for downstream minority residents, agricultural irrigation water and water in characteristic industrial parks, it is sufficient and effective to analyze the multi-scale characteristics of the inflow of the Nanma Reservoir, and to effectively regulate the runoff of the Nanma River. It is of great significance to solve the irrigation and water supply of the secondary terraces on the banks of the Nanma River and the water supply of the characteristic industrial parks in Luanchuan county, as well as to improve the production and living conditions of local residents and promote the sustainable economic and social development of the region.



2. Research methods and sources

In order to fully understand the multi-scale characteristics of the inflow of the Nanma Reservoir, this paper selects the monthly runoff sequence of the reservoir from 1960 to 2004. Firstly, the annual interannual variation of runoff is analyzed. Then, the runoff sequence is smoothed by Empirical Mode Decomposition (EMD) [4], and some natural modal function components of different scales are obtained, namely Intrinsic Mode Function, IMF; finally use Hilbert-Huang transform [5], Mann-Kendall (MK) mutation test [6,7] and Rescaled Range Analysis (R/S) method [8,9] for the different IMF components of annual runoff, analyze its periodicity, mutation and persistence.

2.1 Empirical Mode Decomposition and Hilbert-Huang Transform

The calculation steps are as follows:

(a) Determine the local maximum sequence $X_{\max}(t)$ and the minimum sequence $X_{\min}(t)$ of the time series $X(t)$, and use the cubic spline function to calculate the difference between the $X_{\max}(t)$ and $X_{\min}(t)$ sequences to obtain the upper envelope $U(t)$ and the lower envelope $L(t)$ of the time series $X(t)$. The average curves $M(t)$ of the upper and lower envelopes are as follow:

(b) The remainder of the time series $X(t)$ minus $M(t)$ is denoted as $H_1(t)$:

If $H_1(t)$ satisfies: (1) the maximum value, the minimum value point and the zero crossing point are equal or at most one point difference; (2) at any time point, the mean value of the upper and lower envelopes is zero. Then $H_1(t)$ is an IMF. If the above two conditions are not met, then steps (1) and (2) are repeated as $H_1(t)$ for the new time series until the obtained $H_k(t)$ satisfies the two conditions of the IMF, the first component $C_1(t)$ of time series is extracted.

(c) The remainder of the time series $X(t)$ minus $C_1(t)$ is denoted as $R_1(t)$:

The process (1)~(2) is repeated for the remaining part $R_1(t)$, and when the last remaining part is a monotonous sequence, the decomposition is ended, and the sequence is the trend term of the time series $X(t)$. Usually the standard deviation SD of the two $H(t)$ is used as the basis for ending the decomposition process:

The value of SD is between 0.2 and 0.3.

(d) Hilbert transform of the calculated IMF component:

The instantaneous frequency $f_i(t)$ obtained after HHT changes of different IMF components is:

Where

The period of different IMF components is set as T_i :

2.2 Mann-Kendall (M-K) Mutation Test Method

The calculation process is as follows:

(a) Calculate the order sequence S_k of the time series x with n samples in the sequential case:

(b) Calculate the UF_k statistic corresponding to the sequential time series:

Where $UF_1 = 0$, $E(S_k)$ and $\text{var}(S_k)$ are the mean and variance of S_k , respectively.

(c) The order sequence S_k corresponding to the time series in the reverse order case is calculated: Invert the sequential time series x of n samples into x_n, x_{n-1}, \dots, x_1 , and repeat (5-1) to calculate the reverse order sequence S_k .

(d) Calculate the UB_k statistic corresponding to the reverse time series:

Repeat (5-2) according to x_n, x_{n-1}, \dots, x_1 reverse order time series, and make 2.3 rescaling

range method

The calculation steps are as follows:

(a) The drought time series $X(t)$ with the number of samples N is equally divided into M consecutive sub-sequences of length n ($n \geq 3$, n is an integer), each sub-sequence is denoted as D_m ($m = 1, 2, 3, \dots, M$), and its corresponding element is $x_{k,m}$ ($k = 1, 2, 3, \dots, n$);

(b) Calculate the cumulative dispersion $X(k, m)$ of each subsequence, that is:

Where \bar{x}_m is the mean of the subsequence D_m .

(c) Calculate the range R_m and standard deviation S_m of D_m from $X(k, m)$:

Then, divide R_m by S_m , repeat the above steps to obtain the remarks of the M subsequences, and finally averaging the M refractions to obtain the subscript length of the sequence when the length of the subsequence is n :

(d) Gradually increasing the value of n , and $n \leq N/2$, repeating the calculation steps of (1) to (3) above to finally obtain a series of repetitive range extreme values of the sequence $X(t)$, and the remarking range satisfies the following equation:

For the two sides of the upper equal sign, take the base 10 logarithm at the same time:

Where a is a constant and H is the Hurst exponent, and $0 \leq H \leq 1$.

By plotting the point on the diagram with $\lg n$ as the abscissa and $\lg(R/S)$ as the ordinate, the least square method is used to fit the scatter to get the linear equation. The slope of the line is the Hurst exponent.

3. Results and Analysis

3.1 Characteristics of reservoir changes during the year

Calculate the average monthly runoff of the Nanma Reservoir from 1960 to 2004, and obtain the distribution of monthly runoff during the year. It can be seen from Figure 1 that the distribution of the reservoir runoff during the year is extremely uneven, and the distribution curve during the year is "single peak type", and the peak concentration is in July and August. The runoff from January to May is less than 500,000 m³, and the runoff in the second half of the year is significantly larger than the first half. Table 1 shows that the average runoff of the Nanma Reservoir in July and August accounted for 17.65% and 18.47% of the annual average runoff, respectively. The monthly runoff is mainly concentrated from July to October, accounting for 62.61% of the annual average runoff, and the runoff from June to December in the second half of the year accounts for 85.61% of the annual average runoff. From the seasons, most of the summer and autumn precipitation, the corresponding runoff accounted for 45.36% and 35.08% of the annual runoff. It is 12.08% in winter and only 6.88% in spring. It can be seen that the inflow runoff of the reservoir has obvious seasonal characteristics, and the runoff is mainly the source of water in the flood season.

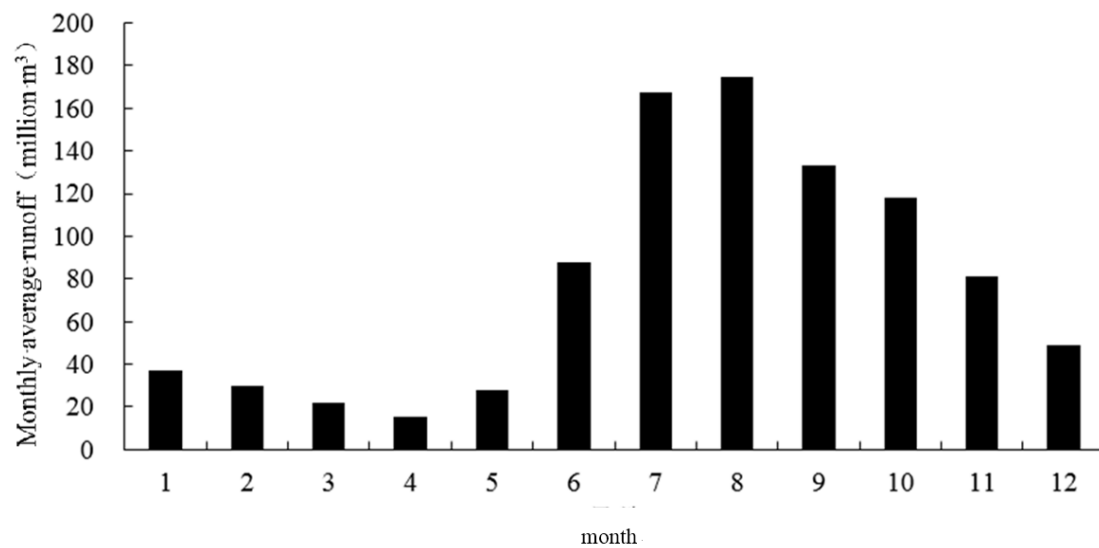


Fig.1 The inflow runoff distribution in a year of Nanma reservoir

Tab.1 The percentage of monthly and seasonal runoff accounts for annual mean runoff at the Nanma reservoir

month	1	2	3	4	5	6	7	8	9	10	11	12
(%)	3.88	3.11	2.31	1.62	2.95	9.23	17.65	18.47	14.05	12.44	8.59	5.18
season	spring			summer			autum		winter			
(%)	6.88			45.36			35.08		12.08			

3.2 Interannual variation characteristics of reservoir runoff

The annual variation of the annual runoff of the Nanma Reservoir is small. The annual runoff variation coefficient C_v is 0.2 and the extreme ratio is 2.56. In order to further analyze the change of the annual runoff of the reservoir, the runoff anomaly bar graph was drawn and the annual runoff trend was fitted according to the linear regression method (see Figure 2). Figure 2 shows that the annual runoff of the Nanma Reservoir before 1972 was less than the multi-year average. The year after the 1972 annual runoff was greater than the mean. The runoff trend line shows that the annual runoff of the Nanma Reservoir has increased with time. trend. After accumulating the runoff anomalies in each year (see Figure 3), it is found that the annual runoff series of the Nanma Reservoir can be roughly divided into two stages: the cumulative runoff of runoff decreases from 1960 to 1972, and the reservoir is in the dry season; the runoff accumulation from 1972 to 2004 The anomaly is on the rise, and the reservoir is dominated by the flood season.

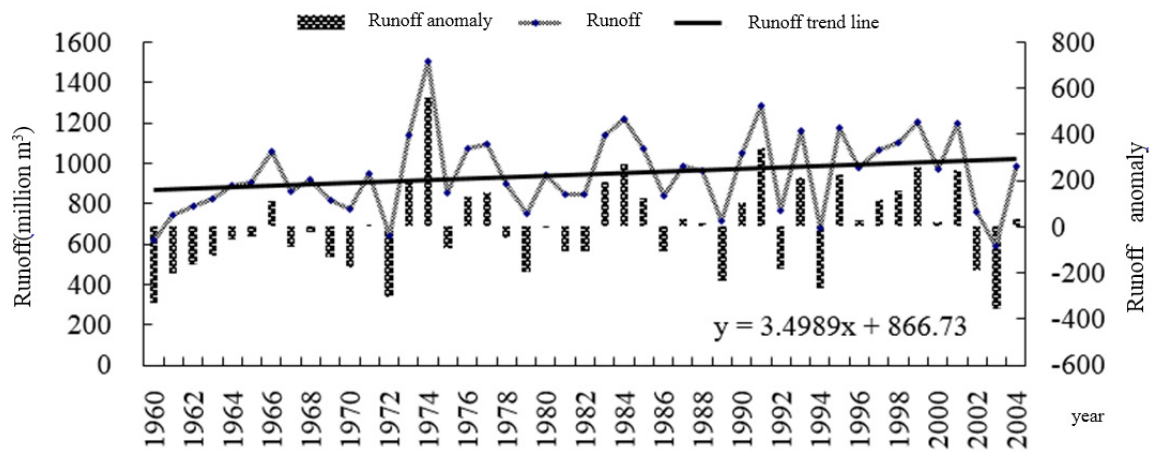


Fig.2 The inter annual variation curve of inflow runoff at Nanma reservoir

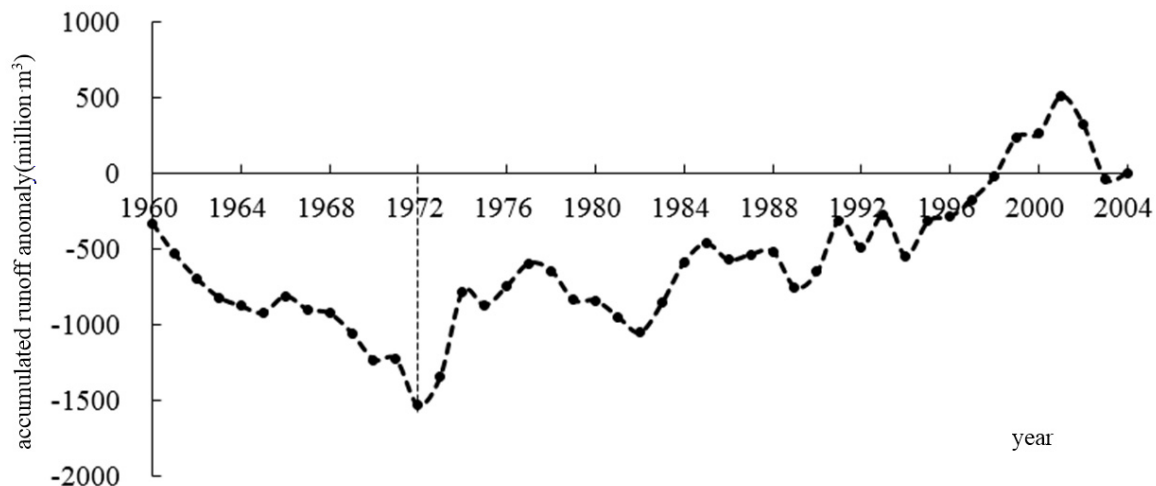


Fig.3 The cumulative anomaly curve of annual inflow runoff at Nanma reservoir

3.3 Multi-scale characteristics analysis of annual runoff of reservoir

The EMD method is used to decompose the annual runoff of the Nanma Reservoir, and the original non-stationary runoff series are sequentially decomposed to obtain multiple stationary sequences, which is more conducive to the discovery of the original runoff, that is, the hidden information in the actual runoff sequence.

3.3.1 Periodic

The EMD decomposition results of the annual runoff series of the Nanma Reservoir are shown in Figure 4. It can be seen from Figure 4 that the annual runoff decomposition of the Nanma Reservoir has four intrinsic mode functions (IMF) and one monotonically increasing trend term. The multiple IMF components reflect the multi-scale characteristics of the annual runoff of the reservoir over time. The trend term indicates that the reservoir runoff has an increasing trend with time, which is consistent with the above results based on linear regression analysis.

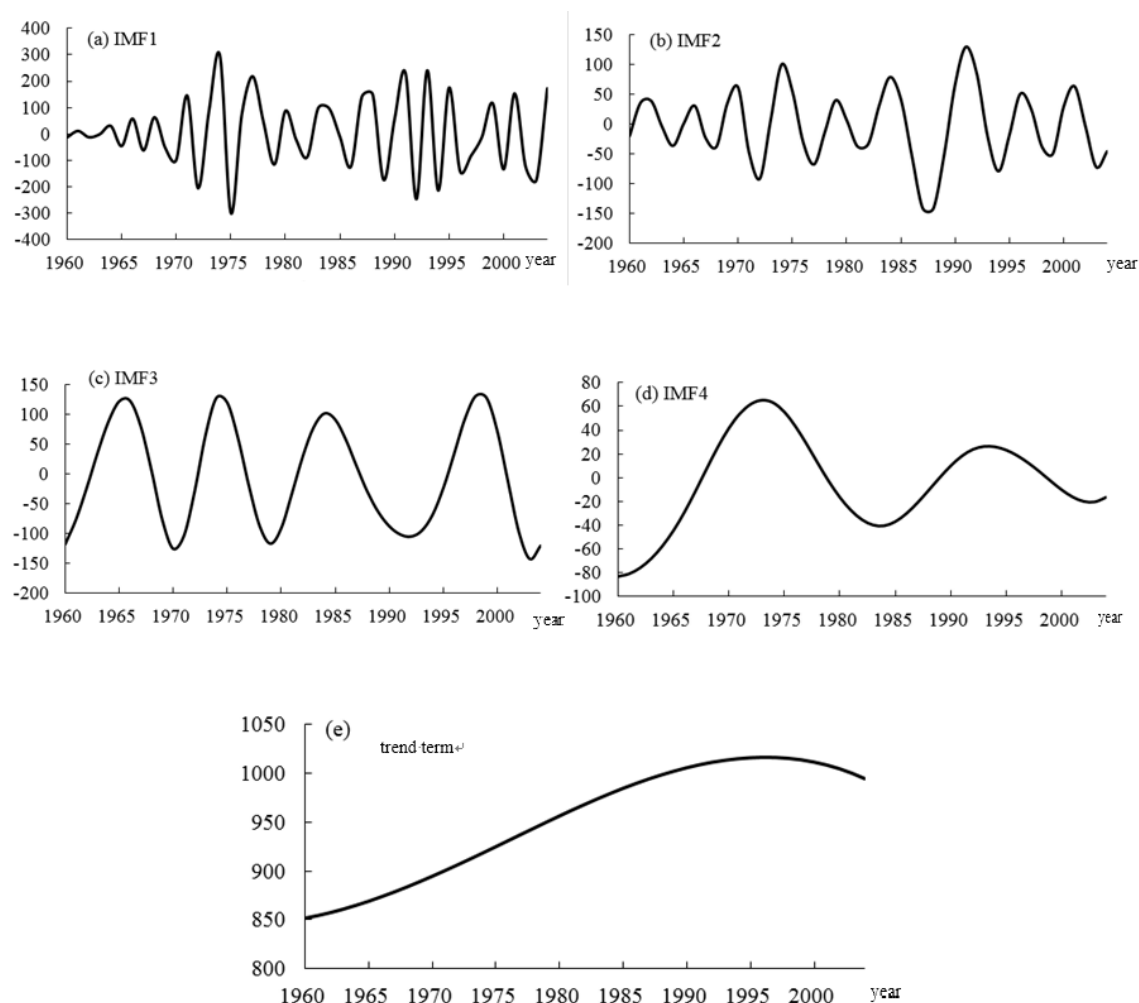


Fig.4 EMD results of annual inflow runoff at Nanma reservoir

The average period is calculated for each order IMF component according to the Hilbert-huang transform method. The results are shown in Table 2. It can be seen from Table 2 that the time fluctuation of the annual runoff of the reservoir may have a quasi-period of 2.4a, 3a, 6a, and 12a.

Tab.2 Each IMF variations periods of annual inflow runoff at Nanma reservoir

	IMF1	IMF2	IMF3	IMF4
period (a)	2.4	3.1	6.1	11.8

3.3.2 Mutagenicity

In order to analyze the abrupt characteristics of reservoir runoff, the M-K mutation curves are plotted for each order of IMF components, as shown in Figure 5. The test principle of the M-K method is: if the positive sequence curve $UF > 0$, the research factor has an increasing trend. If $UF < 0$, the research factor has a decreasing trend. Given the significance level α , if the UF curve exceeds the confidence level $U\alpha$, the trend of increasing or decreasing the research factor is considered to be significant, and the intersection between the UF and the inverse sequence UB at the confidence level is the mutation time point [10]. Here, $\alpha=0.05$ is selected as the confidence test interval. It can be seen from the changes of the UF curve in Figure 5(a), (c), and (d) that the UF values of the IMF1, IMF3, and IMF4 components obtained by the runoff decomposition are substantially larger than zero or fluctuate around zero, indicating that the three components are present. The upward trend and the IMF4

component increased significantly between 1964 and 1984. Figure 5(b) shows that the IMF2 component has a downward trend year by year. Figures 5(a), (b), and (c) have multiple intersections, indicating that the mutations of the first three components obtained by annual runoff decomposition are not obvious. The intersection of UF and UB in Figure 5(d) indicates that the fourth component IMF4 obtained by annual runoff decomposition was mutated in 1961.

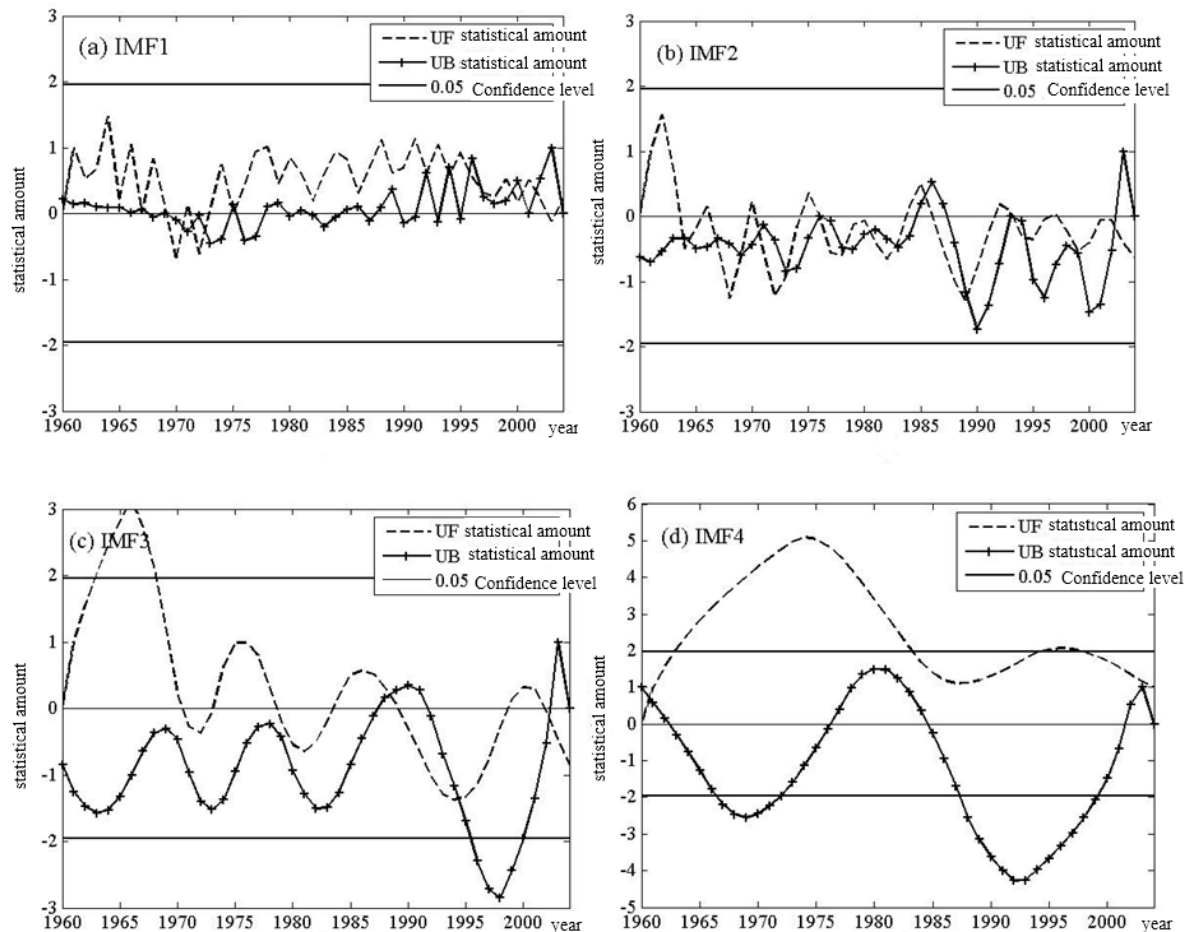


Fig.5 The mutation of each IMF variations of annual inflow runoff at Nanma reservoir

3.3.3 Trend

The linear trend method can only show that the existing research variables have risen or decreased in a certain period of time, and the R/S rule analyzes its future trends according to the existing data. The basis for its discrimination is the Hurst (H) index size [11]. When $0 \leq H < 0.5$, it indicates that the future trend of the runoff sequence is opposite to that of the past, that is, it is anti-sustainability. When $H = 0.5$, it indicates that the runoff sequence is a completely independent random sequence, and the future trend is not affected by the past. When $0.5 \leq H \leq 1$, it indicates that the future trend of the runoff sequence is the same as that of the past, that is, it is positive.

After the annual diameter of the Nanma Reservoir is decomposed by EMD, multiple IMF components are obtained, which indicates that the runoff of the reservoir is unstable. The R/S method is used to select different interval lengths for different IMF components, and the Hurst index value is calculated. (See table 3).

Table 3 shows that among the four IMF components after the annual diameter of the Nanma Reservoir, the Hurst index of the IMF1 component is less than 0.5, and the other three components are greater than 0.5, which indicates that the annual runoff sequence of Nanma reservoir has the

characteristics of positive long range correlation and continuity, that is, the overall change of annual runoff in a certain period of time in the future is consistent with the trend of the past. The trend line in Figure 2 and the trend term after the EMD decomposition of the annual run in Figure 4 indicate that the annual runoff is increasing year by year from 1960 to 2004. It can be seen that the future runoff is likely to continue to increase in the future.

Tab.3 Hurst values of each IMF variations of annual inflow runoff at Nanma reservoir

	IMF1	IMF2	IMF3	IMF4
Hurst	0.461	0.630	0.870	0.983

4. Conclusion

a) The menstrual flow of Nanma Reservoir is unimodal in the year, and the peak value is generally in July and August. The annual inner diameter flow is mainly based on summer precipitation. The interannual variation of runoff is small and has shown an upward trend during the period from 1960 to 2004.

b) The annual runoff of the Nanma Reservoir has non-stationary characteristics and is evident in multiple time scales. After EMD decomposition, the annual runoff has a change period of 2.4a, 3a, 6a and 12a, and the time of mutation is 1961. The development trend of reservoir runoff in the future is the same as that in the study period, that is, it continues to increase year by year.

Acknowledgments

Academician Workstation Construction Special Fund (No.2015IC013);Scientific Research and Technical Innovation Team Construction of Yunnan Province (No.2018HC024).

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