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Analysis on changing characteristic of runoff series of Weihe River

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ABSTRACT

The Weihe River is the largest tributary of the Yellow River. The annual runoff contributes to 80% of ShanXi province's GDP and directly supports 64% of the population of ShanXi province. In order to best maximize water resources management, the runoff series from six hydrologic gauging stations (Huaxian, Lintong, Linjiacun, Xianyang,Zhangjiashan and Weijiabao) are obtained, the Mann–Kendall test, and wavelet transform methods were used to detect the characteristic of runoff variation from 1960 to 2005. The results show that: (1) the runoff present a downward trend over the past 46 years, and the trends are intensified downstream; (2) most of the abrupt changes in runoff appear in the early 1970s, early 1980s to middle 1990s through the result of the Mann–Kendall test; and (3) the annual runoff periods of the WeiHe include 2~4a, 5~6a, 11~14a, 24~26a, respectively. The results of this study imply that less precipitation and warmer climate in the basin are the primary factors that cause this decreasing trend of runoff.

KEYWORDS

HHT; EMD; Abrupt change point; Evolution trend; Approximate periodic; Weihe river.

INTRODUCTION

River runoff is an important part of the hydrological cycle. However, influenced by many factors, such as climate, watershed underlay and human activities, it represents highly complex nonlinear and dynamic characteristics. Recently, traditional data analysis methods like Wavelet transform are widely used due to its good time-frequency localization features and the ability to multi-resolution analysis. But Wavelet transform does not actually get rid of the limitations of Fourier transform, and the signal in wavelet window must be stationary[1]. Specially, wavelet analysis is a method of priori analysis, which selecting different wavelet functions would lead to different interpretations. The HHT, however, directly obtains characteristic components of different scales from the base sequence self-adaption function, accurately reflects the characteristics of the inherent nature of the sequence, and gets better resolution in time-domain and frequency-domain. So HHT is more suitable in handling nonlinear or non-stationary data[2] than the Fourier transform and Wavelet transform.

Weihe basin is a represent of arid and semi-arid regions of China. The study of Weihe River's runoff series has important practical implications. So use HHT method to study the character of Weihe River.

DATA AND THEORETICAL METHODS

Study data

Weihe River, which originating from Bird Mouse Mountain of Weiyuan County in Gansu Provinces, is the largest tributary of the Yellow River, and it was known as the economic lifeline of the Guandong Plain. Due to the climate change and human activities, Weihe basin's surface conditions has changed, which made the natural state of runoff changed too. So it has a very important practical significance[3,4] to research Weihe runoff mutation, evolution characteristics and periods. What is more, it helps us further understand runoff variation rules of the Weihe River and the rational allocation of water resources.

The data for tested was selected a total 46 years's annual runoff series of Linjiacun, Huaxian, Xianyang, Zhangjiashan and Lintong station of Weihe basin from 1960 to 2005.

Introduction of methods

Hilbert-Huang method is a new analysis method of data to handle non-linear, non-stationary series and it is also a signal self-adaptive processing method. This method was proposed by Huang in 1998[5,7]. Hilbert-Huang method consists of EMD (Empirical Mode Decomposition) method and HT (Hilbert transform).

The purpose of the performance of EMD algorithm is that it decomposes a bad signal into a set of better performance of the Intrinsic Mode Function (IMF) with instantaneous frequency, monotonic or an extreme point of the remainder. The self-adaptive method based on the data signal decomposition process local features, does not need preset parameters. By the EMD decomposition, any complex signal can be decomposed as the sum of a finite number of the IMF. The decomposing process of EMD is written as follows: first, get all maximum and minimum of the signal series f(t); second, respectively using cubic spline function to form upper and lower envelope, get the average envelope m1 and then let original series minus m1 to get the new series h1,which no longer contains low frequency series. Generally, h1 is non-stationary, so it is necessary to repeat upper process some tines, in order that average envelope equals close to zero. Then we can get the fist IMF decomposition of value c1, which represent the highest decomposition of original series. And it is written as follows; To continue the decomposition, until we get the rest with a single signal or its value less than the given value in advance, then the decomposition is all.

That is to say, original time series of

f(x) can be defined as follows: $f(t) = \sum_{k=1}^{n} c_k(t) + R(t)$ **(1)**

Where $c_k(t)$ represents each IMF component, $R(t)$ denote the trend term.

Then Hilbert is applied for each IMF component $c_k(t)$:

$$b_k(t) = \frac{1}{\pi} p \int_{-\infty}^{\infty} \frac{c_k(t')}{t-t'} dt' \quad \textbf{(2)}$$

Where P is Cauchy principal value, $c_k(t)$ and $b_k(t)$ can form a complex sequence:

$$z_k(t) = A_k(t)\exp[i\phi_k(t)] \quad \textbf{(3)}$$

Where

$A_k(t) = \sqrt{c_k^2(t) + b_k^2(t)}$ and

$\phi_k(t) = \arctan[b_k(t)/c_k(t)]$.

ABRUPT CHANGE ANALYSIS OF WEIHE BASIN

Overview of abrupt change points detection method

The abrupt change points detection principles of EMD: after decomposition of the high frequency IMF component, calculate its extreme value point, maximum and minimum adjacent points, the absolute value of the amplitude difference and the interval of the maximum and minimum points. The absolute value of extremum difference where biggest and extreme minimum interval is the signal variation point‘s position. Generally, the simplified process of change point is: after the EMD decomposition, calculate directly the first order differential on the high frequency component, and take its modulus; modulus value of the biggest point is the signal variation points.

Abrupt change point analysis

In this paper, runoff series of 6 stations from the year 1960 to 2005 of Weihe basin is analyzed to test the variation. The results are shown in TABLE 1.

According to TABLE 1, there are three most likely variation points (1972, 1982 and 1994) in LinJiacun station; the most likely change points are at 1973, 1981 and 1995 in Xianyang station; 1972, 1982 and 1991 are the most likely change points in Huaxian station; the most possible variation points in Weijiabao sation are1974, 1982 and 1991; 1972, 1982 and 1995 are the most likely variation points in Lintong station and 1972, 1982 and 1995 year are the most possible variation points in Zhangjiashan station.

Studies have shown that extremum year of sunspot has a strong response relationship with variation year. The variation year basically occurs in a same year when sunspot occurs, and each occurrence has a very strong response to ENSO, basically in a strong or very weak years when ENSO occurs. Human activities have an important role in runoff variation, and water conservation measures and water conservancy construction would cause the variation.

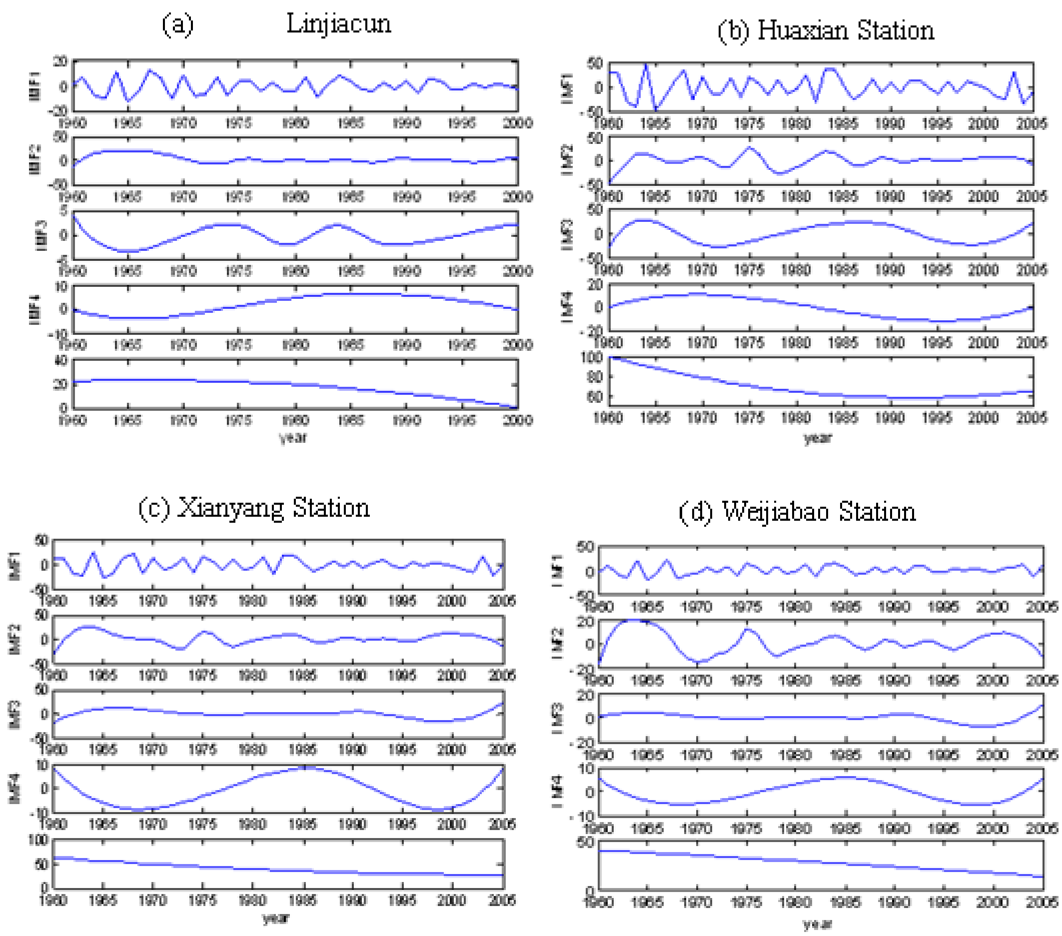
TABLE 1 : Variation points analysis of Weihe basin's 6 stations

Linjia cun	Abrupt Change point: 1972	Year	1971	1972	1973
		Model Value	13.96	17.14	1.47
	Abrupt Change point: 1982	Year	1981	1982	1983
		Model Value	10.63	16.42	11.08
	Abrupt Change point:1994	Year	1993	1994	1995
		Model Value	1.56	6.32	0.58
Hua xian	Abrupt Change point:1972	Year	1971	1972	1973
		Model Value	24.43	61.10	46.15
	Abrupt Change point:1982	Year	1981	1982	1983
		Model Value	56.10	66.29	33.41
	Abrupt Change point:1991	Year	1990	1991	1992
		Model Value	22.4535	24.89	1.16
Xian yang	Abrupt Change point:1973	Year	1972	1973	1974
		Model Value	27.92	30.07	10.74
	Abrupt Change point:1981	Year	1980	1981	1982
		Model Value	35.02	38.73	0.15
	Abrupt Change point:1995	Year	1994	1995	1996
		Model Value	2.75	10.94	8.26
Weijia bao	Abrupt Change point:1974	Year	1973	1974	1975
		Model Value	18.14	23.67	6.99
	Abrupt Change point:1982	Year	1981	1982	1983
		Model Value	22.4	25.87	2.51
	Abrupt Change point:1991	Year	1990	1991	1992
		Model Value	13.04	14.57	0.12
Lintong	Abrupt Change point:1972	Year	1971	1972	1973
		Model Value	1.98	31.61	30.2
	Abrupt Change point:1982	Year	1981	1982	1983
		Model Value	52.83	60.72	0.44
	Abrupt Change point:1995	Year	1994	1995	1996
		Model Value	11.37	23.93	21.89
Zhang jiashan	Abrupt Change	Year	1971	1972	1973
		Model	0.83	13.6	11.9

point:1972	Value			
Abrupt Change point:1982	Year	1981	1982	1983
	Model Value	12.5	13.12	1.76
Abrupt Change point:1995	Year	1994	1995	1996
	Model Value	5.15	5.99	5.32

VARIATION PERIODS ANALYSIS OF RUNOFF IN WEIHE BASIN

HHT method is applied in the multiple time series analysis of annual runoff sequential of 6 hydrometric station in the WeiHe basin, and the IMF component and trend component of each station was got respectively. The figure of decomposition is showed as Figure 1. According to Linjiacun station in Figure 1 (a), first to fourth row are the 4 IMF components of original annual runoff decomposed by EMD and the fifth row is the trend component. And then use a same way to decompose the left stations, and the corresponding results are as follows, Figure 1 (b)-(f).



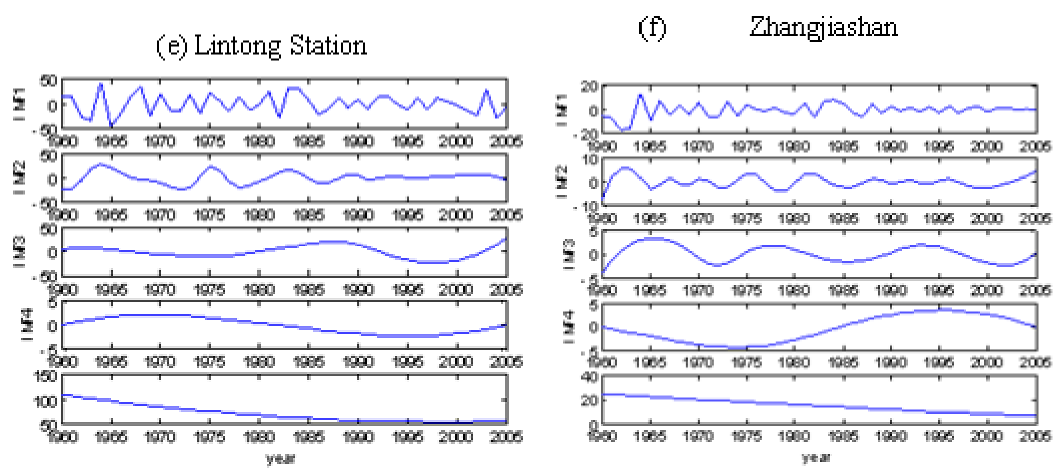


Figure 1 : The EMD and trend decomposition Figure of annual runoff variation of each station in the Weihe basin.

After statistic analysis for each decomposed component, the result of the IMF components of annual runoff series for each station, the corresponding center frequency and the oscillation period was illustrated as TABLE 2.

TABLE 2 : statistics value of Weihe River's annual runoff

Station	Modal	Center frequency /a-1	Average period /a	Station	Modal	Center frequency /a-1	Average period /a
Linjia cun	IMF1	0.43	2.34	Weijiabao	IMF1	0.32	3.12
	IMF2	0.18	5.44		IMF2	0.15	6.67
	IMF3	0.07	13.67		IMF3	0.069	14.38
	IMF4	0.04	24.69		IMF4	0.0367	27.25
Hua xian	IMF1	0.42	2.38	Lin tong	IMF1	0.41	2.43
	IMF2	0.17	5.89		IMF2	0.12	8.42
	IMF3	0.067	11.12		IMF3	0.067	14.93
	IMF4	0.036	27.78		IMF4	0.042	23.81
Xian yang	IMF1	0.33	3.04	Zhang jiashan	IMF1	0.43	2.33
	IMF2	0.169	5.92		IMF2	0.153	6.59
	IMF3	0.07	14.1		IMF3	0.072	14.02
	IMF4	0.037	27.02		IMF4	0.038	26.32

It can be seen from TABLE 2 that the natural runoff of Weihe basin whose center frequency of each IMF component is: 0.43 a^{-1}, 0.18 a^{-1}, 0.07 a^{-1} and 0.04 a^{-1} ordered from high to low-order, while average period is 2.34a, 5.44a, 13.67a and 24.69. All in all, center frequency changes from high to low while average period changes from short to long. Through the analysis, we can conclude that the long-period or short-period fluctuation in the contribution rate is greater than the long-period fluctuation, indicating that long-period or short-period fluctuation component is the main reason for the change in runoff, while the long-period fluctuation component of the change process runoff impacts is mainly reflected in the overall development trends controllability. In the left station, annual runoff shows similar results.

Use the similar way to analyze other station, and we can conclude that:

1) The change process of real runoff for each station shows nonlinear and non-stationary, which is the result of the interaction of a variety of fluctuations components. And it can be decomposed into 4 components with different periods, IMF1 ~ IMF4 and a residual component Res, which reflect complex and multi-time scale characteristics changes of annual runoff in Weihe River.

2) IMF1 component has a period of 2-4 years, IMF2 component 5-6 years, IMF3 component 12-14 years, and IMF4 component 24-26 years.

3) Res component shows attenuation trend of annual runoff for each station in Weihe River. Because of each station in a different location, their respective weather conditions and different surface conditions, the IMF calculated, variation points, major components and the period are quite different on the size, but there exists almost the same change period in the overall Weihe basin, and at different scales there exists about 2-4a, 5-6a, 11-14a and the approximate period of about 24-26a, which may be related to atmospheric circulation and sunspot activity, etc. Existing studies have shown that 2-4 year period is consistent with ENSO phenomenon with a period of 3.5 years[8]; and 11a year period is consistent with sunspot activity and air - sea change period in the strength of the interaction.

CHANGE TRENDS AND MANN-KENDALL TEST

After decomposing annual runoff series with EMD method, we not only get the time scale components of different characteristics, but also get a trend component, which represents the trend of runoff. From the Figure 2 of 6 hydrological stations, It can see that they all have a downward trend. In order to test whether the trend is reasonable, we use Mann-Kendall method to test trend items. Trends change is determined by the statistical test value of Zc. If Zc is positive, runoff series has a upward trend; on the contrary, runoff series has a downward trend. The results are shown in TABLE 3.

TABLE 3 : Annual Runoff Change Trends in Weihe River and Mann-Kendall Test

Station	M-K Test Value ZC	Significant level	Station	M-K Test Value ZC	Significant level
Linjia cun	-4.88	significant	Weijia bao	-2.90	significant
Hua xian	-3.54	significant	Lin tong	-3.62	significant
Xianyang	-4.22	significant	Zhang jia shan	-1.69	significant

Notice: $Z_{0.05}$=1. 64, $Z_{0.01}$= + 1. 96 of Linjiacun, Huaxian, Xianyang, Weijiabao, Lintong and Zhangjiashan station are respectively: -4.88, -3.54, - 4.22, -2.90, -3.62 and -1.69, which all have reached a Si-gnificant level. As can be seen from the above analysis,whether the trend towards items decomposed by EMD decomposition, or the Mann-Kendall test method, it shows that there is a certain degree of decline during 1960 to 2005.

As can be seen from TABLE 3, the value of annual runoff Mann-Kendall statistic Zc

CONCLUSIONS

This paper uses HHT method to analyze the natural runoff series of 6 stations from the year of 1960 to 2005 in Weihe River.

Results are shown as follows.

(1) Variation Analysis

Results have shown that the most possible variation points of Linjiacun Station are respectively the year of 1990, 1990 and 1993; and Xianyang Station, Huaxian Station, Weijiabao Station, Lintong Station and Zhangjiasha Station's most likely variation points are all the year of 1990, 1990 and 1993, too. Weihe River belonged to continental monsoon climate, was affected by the western Pacific subtropical high and ENSO event. What's more, because of typical ElNio event in 1982 and the event of new ENSO in 1994, the precipitation in Weihe River had a significant decline, which formed climate conditions for runoff variation. Cumulative effects of human activities, industrial and agricultural water consumption continues to increase, and climate has also changed, eventually leading to the runoff sudden changes in 1994[6,9].

(2) Period

There are approximate periods evolution with different time scales in Weihe River. Through the statistical analysis of IMF components, Weihe River exists approximate periods that range from 2 to 4a, 5 to

6a, 11 to 14a, and 24 to 26a, approximately; which is consistent with the period that ElNio-La Nina and sunspot activity occur.

(3) Change Trends

Each station Weihe River, the average annual flow has a downward trend in different degrees, and it has significant decreased levels with a confidence level over 95%. For recent 60 years, the overall flow of the Weihe River presents a significant downward trend. Whether the trend towards trend items decomposed by EMD decomposition, or the Mann-Kendall test method, it shows that there is a certain degree of decline during 1960-2005.

So, it can be seen that the sudden change of runoff in Weihe River, period and trend are mainly affected by changes in precipitation, and human activities such as basin soil and water conservation construction. It also needs further research to study various factors on variance contribution rate,which lays the foundation for hydrological analysis in changing environment.

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