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Quantitative Analysis of Annual Precipitation in Extreme Precipitation Areas

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Abstract: This paper analyzed the characteristics of annual changes in areas with extreme rainfall to better understand the precipitation patterns. Trend analysis, cycle analysis and mutation analysis were carried out on the historical precipitation of Zhengzhou stations, so as to describe and analyze the annual variation characteristics of precipitation in Zhengzhou. The trend analysis uses R/S analysis method to show that the precipitation in Zhengzhou shows a strong anti-continuous trend. The cycle analysis adopts the Morlet wavelet analysis method, and the annual average precipitation shows the law of 6a as the first main cycle and 10a as the second main cycle. Mutation analysis was performed by Mann-Kendall method, which showed that the precipitation sequence in Zhengzhou had a mutation during 2013 and that the mutation was significant. The interannual change in precipitation maintains a significant upward trend after a brief downtrend at the breakout point.

1. Introduction

In recent years, many places on earth have encountered extremely heavy rainfall and blizzards. These extreme weather poses a huge threat to the lives, safety and property of local people. In July 2021, Zhengzhou City encountered extreme rainstorms. The cumulative average precipitation reached 449mm, which caused huge losses to the life safety and eco-nomic operation of Zhengzhou people. The lives and normal production of tens of millions of people were severely affected.

Studies have shown that in the context of global warming, the amount, intensity, frequency and type of precipitation in my country are expected to undergo certain changes. The possibility of extreme precipitation will increase. Due to the different topography and landforms of our country, and the combined influence of multiple factors, the precipitation characteristics of different cities are also different. Therefore, it is necessary to establish a prediction model for cities with multiple potential extreme precipitation events and a quantitative analysis model for the loss caused by extreme precipitation.

2. Data and methods

2.1 Data Description

The data in this paper was obtained from the National Oceanic and Atmospheric Ad-ministration of the United States. Before the analysis, we first preprocessed the data, in-cluding culling outliers, adding missing values, and calculating annual precipitation.

2.2 Research Method

a) R/S Analysis Method

Using the time series trend statistical test method R/S analysis method, the Hurst index can be calculated and used to quantitatively describe the continuity of the time series evolution trend, thereby judging the degree of variation of the future trend relative to the past trend.

The basic principle is:

A time series of $\xi(t), t = 1,2, \dots, n$, For any positive integer $\tau \geq 1$,

Define the mean series:

$$\langle \xi \rangle_\tau = \frac{1}{\tau} \sum_{t=1}^{\tau} \xi(t), \tau = 1,2, \dots, n \tag{1.}$$

Cumulative deviation $X(t)$is expressed as:

$$X(t, \tau) = \sum_{u=1}^{t} (\xi(u) - \langle \xi \rangle_\tau), t \in [1, \tau] \tag{2.}$$

Defined range R:

$$R(\tau) = \max_{t \in [1,\tau]} X(t, \tau) - \min_{t \in [1,\tau]} X(t, \tau), \tau = 1,2, \dots, n \tag{3.}$$

Define standard deviation S:

$$S(\tau) = \sqrt{\frac{1}{\tau} \sum_{t=1}^{\tau} (\xi(t) - \langle \xi \rangle_\tau)^2}, \tau = 1,2, \dots, n \tag{4.}$$

When $\xi(t), t = 1,2, \dots, n$, is not a random sequence with independent and limited variance, there must be:

$$\frac{R(\tau)}{S(\tau)} = (c\tau)^H \tag{5.}$$

$$\lg \left(\frac{R}{S} \right)_\tau = H \lg c + H \lg \tau \tag{6.}$$

In the formula, c is a constant and H is the Hurst index.

If the continuity is stronger, the future change trend will be more similar to the past change trend. The meanings of different intervals of the Hurst index are shown in the table below:

Tablet 1: Hurst Index Classification Table

H	Persistence
(0.65,1]	Strong Persistence
(0.5,0.65]	Weak Persistence
(0.35,0.5]	Weak Anti-Persistence
[0,0.35)	Strong Anti-Persistence

b) Morlet wavelet analysis

In this paper, Morlet continuous complex wavelet transform is used to analyze the periodicity of the annual precipitation time series in Zhengzhou. The specific process is as follows:

Given the wavelet function $\psi(t)$:

$$\psi(t) = e^{ict} e^{-\frac{t^2}{2}} \tag{7.}$$

The continuous wavelet transform coefficient $W_f(a,b)$ of hydrological time series $x(t)$:

$$W_f(a,b) = |a|^{-\frac{1}{2}} \int_{-\infty}^{\infty} x(t)\bar{\psi}\left(\frac{t-b}{a}\right) \mathrm{d}t \tag{8.}$$

In the formula, a is the scale factor, which reflects the period length of the wavelet.

Integrate the squares of all wavelet transform coefficients on a in the time domain to obtain the wavelet variance:

$$\mathrm{Var}(a) = \int_{-\infty}^{\infty} \left|W_f(a,b)\right|^2 \mathrm{d}b \tag{9.}$$

The wavelet variance graph obtained by concretizing formula (2) can reflect the distribution of signal fluctuation energy with scale a, and the scale corresponding to the peak is the main period of the sequence.

c) Mann—Kendall method

In this paper, the Mann-Kendall mutation test method is used to test the mutation points of the time series of annual precipitation in Zhengzhou.

Construct a sequence of time series:

$$T_k = \sum_{i=1}^{k} r_i \quad r_i = \begin{cases} 1, & x_i > x_j \\ 0, & else \end{cases} \quad j = 1, 2, \cdots, i \tag{10.}$$

Define the order statistics:

$$UF_k = \frac{T_k - E(T_k)}{\sqrt{\mathrm{Var}\,(T_k)}} \quad k = 1, 2, \cdots, n \tag{11.}$$

At this time, the sequence x is reversed, and the reverse statistic UB is calculated in the same way, and at the same time, let$UB_k = -UF_k\,(k = n, n-1, \cdots, 1)$, $UB_1 = 0$. Plot UF_k and UB_k on the same graph. If the two curves of UF_k or UB_k are higher than the critical line, it indicates that the upward or downward trend is significant; if UF_k and UB_k intersect .And the intersection point is between the critical lines, then the time point corresponding to the intersection point is the time point when the mutation occurs, and the mutation is significant.

3. Characteristics of annual changes in precipitation

3.1 Trend

The R/S analysis of the average precipitation series in Zhengzhou from 1957 to 2020 results in a Hurst index of 0.2414, indicating that the evolution trend is strongly anti-continuous, that is, the precipitation time series have long-term correlation, but the over-all trend in the future is opposite to the past.

3.2 Period

Using Morlet wavelet analysis and running the program through MATLAB, the contour map of the real part of the wavelet coefficients of the average precipitation in Zhengzhou from 1957 to 2020 is obtained, as shown in the figure below. The time scales of 2-6a, 5-7a, and 8-12a are more obvious. The center dimensions are approximately 4a, 6a, and 10a, re-spectively. The 6a scale contour changes most frequently, indicating that there are obvious fluctuations in the annual average precipitation on this time scale.

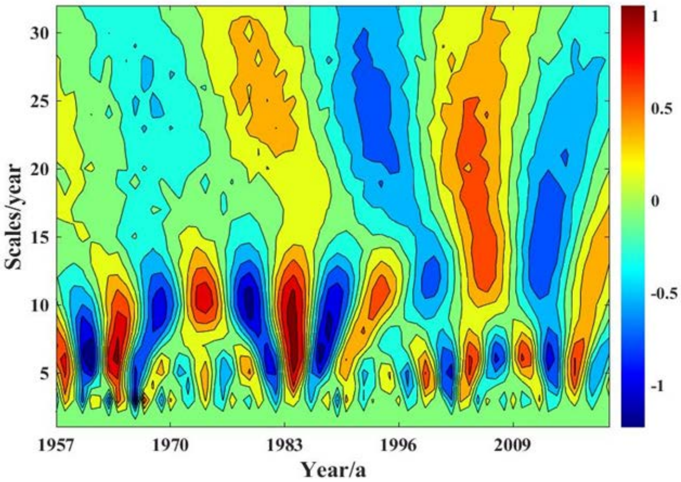

Figure 1: Contour map of real part of wavelet coefficients of average precipitation in Zhengzhou

According to the figure below, it can be seen that the annual average precipitation in Zhengzhou has periodic changes of different scales. There are two obvious extreme values in the wavelet variance graph, which are 6a and 10a. Among them, the extreme value corre-sponding to the 6a time scale is the largest, indicating that the cyclical fluctuations around 6a are the strongest, which is the first major cycle of the average precipitation change, that is, the average rainfall of Zhengzhou from 1957 to 2020 has a major cycle of 6a changes. The fluctuation of this cycle determines the characteristics of the annual rainfall in the area; 10a is the second main cycle. Although the time scale of cycle 4a is obvious, its wavelet variance has no obvious extreme value. Therefore, taking 4a as the average precipitation cycle of Zhengzhou from 1957 to 2020 is not sufficiently representative.

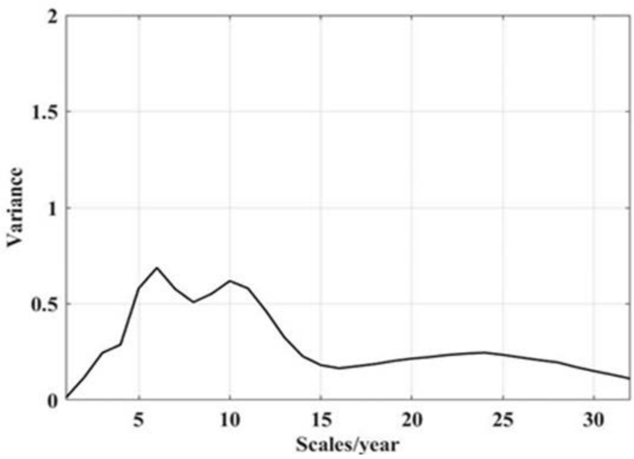

Figure 2: Wavelet variance map of average precipitation in Zhengzhou from 1957 to 2020

3.3 Mutagenicity

Under the condition of a significance level of 0.05, the MK mutation test method detects that the Zhengzhou precipitation sequence has a mutation in 2013, and the intersection of UFk and UBk falls within the critical line, indicating the mutation Signifi-cantly. And we found that Zhengzhou's UBk curve changes significantly after the point of intersection, indicating that the inter-annual variation of precipitation has maintained a sig-nificant upward trend after a short-term downward trend since the breakthrough point.

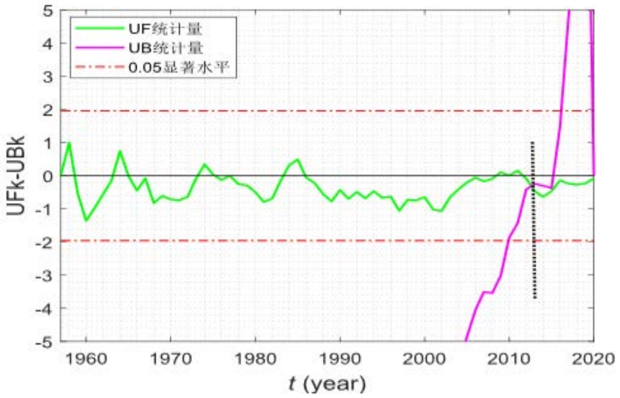

Figure 3: Interannual Abrupt Change of Average Precipitation from 1957 to 2020

4. Conclusions

By using a variety of methods to analyze the historical rainfall in Zhengzhou, we found that the precipitation in Zhengzhou showed a strong anti-sustainability. The average annual precipitation of Zhengzhou city shows a law of 6a as the first main cycle and 10a as the second main cycle. Mutations show that the precipitation sequence in Zhengzhou underwent a mutation during 2013, and the mutation was significant. The interannual change in precipitation maintains a significant upward trend after a brief downtrend at the breakout point.

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