Trend Analysis and Periodicity Analysis of Annual Precipitation in Dongxi River Basin of Xiamen

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Abstract. Precipitation is an important part of hydrology, which is of great significance to local water resources allocation and farmland irrigation. This study uses the Dongxi River basin in Xiamen City as the research area. Based on the precipitation series data from 1956 to 2015, the Mann-Kendall test, linear regression method, Sen's slope estimation and wavelet analysis are used to analyze the trend and periodicity of precipitation. The results show that precipitation generally followed a small rise over a period of 60 years. The Mann-Kendall test detected several possible change points, but they can only indicate that the precipitation in the basin changes frequently. In addition, wavelet analysis reveals that the annual precipitation series have main periods of 4a, 12a, 30a, and 49 a, and on the time scale of the first main period, the precipitation has undergone two wet and dry transitions between 1956 and 2015. Our results reveal the trend and periodicity of precipitation in Dongxi River basin, which is conducive to the optimization of local water resources allocation, and provides scientific support for subsequent agricultural water conservancy project application and ecological construction.

1. Introduction

In recent years, with the global warming, more and more attention has been paid to the possible impact of climate change, and a lot of studies on the trend analysis of climatological variables have been launched[1]. According to the updated results of the IPCC Fourth Assessment Report, precipitation is one of the most investigated climatological variables[2]. Precipitation is a major component of the water cycle, and its changes will directly or indirectly affect freshwater supply, agricultural irrigation and water resources management[3-5].

At present, a variety of mature methods have been applied to analyze the trend of precipitation and other variables. Asfaw et al. used Mann-Kendall test to detect the time series trend analysis of rainfall and temperature, which provided a basis for assessing climate change and proposed feasible adaptation strategies [6]. Wu and Qian selected an innovative trend analysis (ITA), Mann-Kendall test and linear regression analysis to study the trends in annual and seasonal rainfall at 14 rainfall stations in Shaanxi Province, China [7]. In addition, Gocic and Trajkovic used the non-parametric Mann-Kendall and Sen's tests to analyze the annual and seasonal trends of seven meteorological variables for twelve weather stations in Serbia during 1980-2010, and revealed that the results of using the Mann-Kendall and Sen's tests proved the good consistency of performance in detecting the trend of meteorological variables[8]. Feng et al. applied Mann-Kendall test, linear trend, Morlet wavelet analysis and inverse distance weighting interpolation methods to investigate temporal and spatial variation of ET computed by FAO-56 Penman-Monteith model for 119 stations in Southwest China during the period of 1954-2013[9].
The above trend analysis methods all focus on large and medium-sized basins or larger areas, and are less applied to small basins. Dongxi River basin is a small basin in Xiamen, but it plays an important role in the local area. Although Xiamen, as a special economic zone, is a coastal city, there is a serious shortage of fresh water resources in the territory. The annual water resources per person in Xiamen is 319 m$^3$, only reached 15% of the national average, and far below the internationally recognized warning line of 1700 m$^3$ per person per year[10-11]. Production and living water comes mainly from the Dongxi River, the water source is so single that there are certain hidden dangers in water supply security. Therefore, studying the characteristics of precipitation changes in the Dongxi River Basin is of great significance to the allocation of local water resources.

The main goal of this study was to assess the trend and periodicity of annual precipitation in Dongxi River basin for the period 1956-2015 using different methods in order to provide scientific reference for the sustainable use of local water resources and agricultural development. The rest of this paper is organized as follows: immediately below the study area, the data sources and methods used in this research are introduced. The next section discusses the results of various methods, especially the result of wavelet analysis. Finally, the conclusion and acknowledgement are drawn.

2. Study area
The Dongxi River is the largest river in the territory of Xiamen, located in the subtropical monsoon climate zone, mild climate, abundant rainfall, adequate heat. It has rich climate resources for the development of agriculture, forestry, animal husbandry and fishery. After Dongxi and Xixi converge at Shuangxikou, Tong’an district, Xiamen, they flow to Tuanjiedai and are divided into Pusheng tributaries and Shixun tributaries, and then merge into Tong’an Bay. The watershed has an area of approximately 491.48 km$^2$ and the river length is 34 km.

3. Data and methods

3.1 Precipitation data
The historical data used in this study was obtained from 5 precipitation stations (Wangqian, Xinghou, Wufeng, Zhushan, Yinhu) located in the Dongxi River basin from 1956 to 2015. The areal precipitation series were computed by the Thiessen polygon method for subsequent analysis.

3.2 Methods
The approximate trend of the annual precipitation trend is analyzed by linear regression, the significance level of the trend is evaluated by Mann-Kendall (MK) test [12-13], and the magnitude of the trend is calculated by Sen's slope estimator [14], the change point is calculated by MK mutation detection, and the wavelet analysis is used to determine the periodicity.

3.2.1 Linear regression. Linear regression is a mathematical equation that analyzes the relationship between two variables to establish a linear regression relationship to determine the trend of the data[15].

3.2.2 Mann-Kendall test. Mann-Kendall method is a non-parametric statistical test which has the advantages of simple calculation and not being disturbed by a few outliers, this procedure allows testing non-linear trends and turning points [16]. Since the sample using this method does not need to follow a certain distribution, MK test is suitable for common non-normally distributed data in hydrology, meteorology, climate and other fields.

3.2.3 Sen’s slope estimator. Although the MK test can verify the existence of a trend and can indicate the direction of the trend, it cannot visually display the magnitude of the trend change. For this reason, Sen's slope estimator is introduced, which estimates the change per unit time with a linear trend[17]. Sen’s slope estimator is a non-parametric method, and hydrological data is usually non-normally
distributed, which makes Sen’s slope estimator a good trend analysis method that can replace the widely used Ordinary Least Squares[18-19]. The formula for calculating the estimator is as follows:

\[ Q = \text{Median} \left\{ \frac{x_j - x_i}{j - i} \right\}, \text{ for } i=1,\ldots,N \]  

(1)

Where Q is the slope, \(x_j\) and \(x_i\) represent the values of time j and i (j>i) respectively, and N is the number of time periods representing the total amount of each precipitation value. The trend is the median of the slope between each data point and the next data point.

3.2.4 Wavelet analysis. Wavelet analysis takes time and frequency as two independent variable, and expands one dimensional signals in both time and frequency directions, so as to clearly understand the frequency characteristics of different time domains of the time series, and also understand the time distribution characteristics of different frequencies. For \(f(t) \in L^2(R)\), the Continuous Wavelet Transform (CWT) is given by the following equation:

\[ W_f(a,b) = \left| a \right|^{-\frac{1}{2}} \int_{-\infty}^{\infty} f(t) \overline{\varphi} \left( \frac{t-b}{a} \right) dt \]  

(2)

Where \(a\) represents scale factor, \(b\) represents time factor, \(\varphi\) denotes the mother wavelet, \(\overline{\varphi}(t)\) indicates a complex conjugate. Morlet wavelet is a complex wavelet. In this study, the Morlet wavelet has been applied as the mother wavelet, which is defined as:

\[ \varphi(t) = e^{-t^2/2} e^{i\omega_0 t} \]  

(3)

Where t denotes dimensionless time and \(\omega_0(\omega_0=6)\) is a dimensionless frequency[20]. The research is implemented by MATLAB software.

4. Results

4.1 Trend analysis

4.1.1 Linear regression. As shown in Figure 1, although more precipitation fluctuations, but no clear upward or downward trend. In general, the linear regression equation obtained is \(y = -0.4248x + 2790.8\), which indicates that the annual precipitation in the basin is generally decreasing.

Figure 1. Linear regression of precipitation

4.1.2 Mann-Kendall test and Sen’s slope estimator. The statistical value \(Z\) of annual precipitation calculated by the M-K method is 0.31. Although the Z value is less than 1.28, which indicates that the significance test with a reliability of 90% has not passed, the positive value of \(Z\) indicates an upward trend of annual precipitation. The Sen’s Slope value for Dongxi River is 1.04 which means Dongxi River has increasing rainfall trend at 1.04 mm per year and the amplitude is not obvious. This conclusion
is inconsistent with the conclusion that the annual precipitation shows an insignificant decreasing trend obtained by linear trend line analysis.

4.2 Change point analysis
Through the MK mutation test, the UF and UB curves are drawn out (Figure 2). As shown in Figure 2, the UF and UB curves intersect many times during the entire time period, but the UF curves are almost all within the critical line ($\alpha=0.05$), indicating that there is no change point in the precipitation sequence. Multiple intersections can only indicate that the precipitation in the basin changes frequently.

![Figure 2. MK mutation analysis of precipitation](image)

4.3 Periodicity analysis
In order to understand the cyclical change characteristics of precipitation, the contour map of real part of wavelet coefficients was drawn after the precipitation sequence anomalies in the Dongxi River basin from 1956 to 2015 were flattened (Figure 3). And draw a wavelet variance map (Figure 4) to find the major and minor cycles of the precipitation series more objectively.

The contour map of real part of wavelet coefficients can reflect the periodic changes of the precipitation sequence at different time scales and the distribution in the time domain. The results showed that annual precipitation exhibits different periodic alternating phenomena, with three types of oscillation periods of 25a-44a, 8a-13a, and 2a-6a. At the time scale of 30a, the change point of precipitation occurred approximately every 20a, and the wet period mainly appeared primarily in 1956-1975 and 1995-2015. According to the figure 3, it can be predicted that at the time scale of 30 a, there will still be more precipitation in 2016 and 2017, and then the precipitation will start to decline again.

The wavelet variance graph can reflect the fluctuation of the precipitation sequence and the change of energy with time. Therefore, it is mostly used to explore the change process of the main cycle in the evolution of annual precipitation. Seen from the Figure 4, there are four distinct extreme values are arranged in ascending order corresponding to 4a, 12a, 30a, and 49a time scale. The year 30a corresponding to the maximum peak value is the first main cycle, indicating that the precipitation evolution with 30a as a cycle is the most obvious, controlling the variation characteristics of precipitation in Dongxi River during the entire time period. The peaks corresponding to the time scales of 12a, 49a, and 4a are much smaller than the corresponding values of the first cycle, so these three time scales are the second, third, and fourth cycles, respectively.
Figure 3. Contour map of real part of wavelet coefficients

Figure 4. Wavelet variance graph

5. Conclusion
Comparing the three trend analysis methods to study the precipitation in the Dongxi River basin, it is found that the precipitation in the linear regression method shows an insignificant downward trend. The results obtained by the MK method and Sen's slope method are consistent, indicating that the precipitation is showing an upward trend in general. According to the MK method, the significance level of the trend does not pass the 99%, 95%, and 90% confidence intervals. The MK results also show that there is no real mutation point in the precipitation in the Dongxi River basin from 1956 to 2015, and the multiple intersections are just frequent changes in precipitation in the basin. The results of wavelet analysis show that the annual precipitation series have main periods of 4a, 12a, 30a, and 49 a. On the time scale of the first main period of 30 a, the precipitation has undergone two wet and dry transitions between 1956 and 2015, and it is predicted that the precipitation in the basin will still be abundant from 2016 to 2017. The results of this study are helpful for the government and local agricultural management departments to rationally plan and use water resources and prevent the shortage of irrigation water for farmland.

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