Predictive Analysis of Characteristic Variation and Evolution of Rainfall Cycle in Guangzhou

Pei Liu¹, Wei Xu¹*, Huang Pengfei¹

¹ Department of River & Coastal Engineering of The Pearl River Hydraulic Research Institute, 510000, China
²linzhy3@mail2.sysu.edu.cn
* Corresponding Author: Wei Xu; email: 1130088375@qq.com; phone: 18688455686; fax: 020-85116617

Abstract. Due to the influences of global warming, urban rainfall has changed significantly. Based on the annual rainfall data of Guangzhou from 1952 to 2019, the characteristics of interannual variation are statistically analyzed. The periodic characteristics of rainfall variation and its development trend prediction are studied by using non-parametric Mann-Kendall test, wavelet analysis and neural network methods. The results show that: After 1993, there was an increasing trend of rainfall in Guangzhou, and a sudden change in 2009, and the increasing trend of rainfall became more obvious. The 30a cycle scale of rainfall in Guangzhou shows the most significance. The average cycle of rainfall changes is around 19a. The rainfall in Guangzhou in 2020 is predicted to be 2,628.9mm, and the rainfall will be in "dry water" period from 2021 to 2029. The rainfall characteristics in Guangzhou are continuously changing under the influence of climate warming. This study is of great significance to reveal the recent drought and flood characteristics of the region.

1. Introduction
In recent years, global warming has caused obvious heat island effects in areas with a higher degree of urbanization, which are the main warming areas. Guangzhou is located in the hinterland of the Pearl River Delta region. With the rapid economic development and the accelerating urbanization process, the greenhouse gas emissions have increased rapidly. Related research on Guangzhou’s climate warming has shown that the degree of climate warming in Guangzhou is higher than the provincial and national averages. However, it has become more obvious in recent years, leading to an increasing number of extreme weather events in Guangzhou [1,2]. According to the study, precipitation in Guangzhou has different periodic oscillations, and the continuity and intermittence of drought and flood events in the pre-flood season in Guangzhou are more obvious than that in the post-flood season [3,4]. At present, although many domestic research achievements have been made in the temporal and spatial variations of drought and flood in China, due to geographical and climatic differences[5,6], the long-term changes of drought and flood in different parts of China have different characteristics, so it is of great significance to further study the characteristics of precipitation changes.

To this end, this paper uses the non-parametric Mann-Kendall test, wavelet analysis and neural network, which are widely used in recent years, to carry out multi-time scale statistical analysis on the precipitation data of Guangzhou for many years, and study the periodic characteristics of rainfall variation and its development trend prediction, so as to explain the various variation periods of rainfall.
hidden in the time series in Guangzhou, fully reflect the variation trend of rainfall in different time scales, and reveal the future development trend of precipitation in Guangzhou City for qualitative estimation and qualitative verification.

2. Data and research methods
The meteorological data of Guangzhou from 1952 to 2019 selected in this paper are from the daily data set of China's surface climate data of the China Meteorological Science Data Sharing Service Network. The main research methods used in this paper include non-parametric Mann-Kendall test, wavelet analysis and neural network prediction.

   Mann Kendall test is one of the time series trend analysis methods recommended by the World Meteorological Organization and widely used in the study of hydrological variation trend. Mann Kendall analysis trend is judged by constructing a rank sequence and defining the size of statistical variable UFk. If UFk > 0, it indicates that the sequence has an upward trend; If UFk < 0, it shows a downward trend in the sequence. Given a significance level a, if UFk > Ua/2, the sequence trend is significant. Arrange the time series X in the reverse order, and calculate the statistic UBk. If the intersection point occurs between UFk and UBk, and the intersection point is between the critical lines, then the time when the mutation starts is the corresponding time of the intersection point [7].

   The basic idea of wavelet analysis is to use a cluster of wavelet functions to represent or approximate a certain signal function. Therefore, wavelet function is the key of wavelet analysis. It is a kind of function with oscillatory and can decay to zero rapidly. The basic principle of wavelet analysis is to obtain the low-frequency or high-frequency information of the signal by increasing or decreasing the scale a, and then analyze the general situation or details of the signal to realize the analysis of the local characteristics of different time scales and spaces. In practical research, the most important thing is to get the wavelet coefficients from the wavelet transform equation, and then use these coefficients to analyze the time-frequency characteristics of time series. By integrating the square value of wavelet coefficients in B domain, the wavelet variance can be obtained, which can reflect the distribution of energy of signal fluctuation with scale. Therefore, the wavelet variance diagram can be used to determine the relative strength of different scale disturbances in signals and the main time scale of existence, i.e. the main cycle[8,9].

   Neural network is a nonlinear and self-adaptive information processing system composed of a large number of processing units interconnected. It is proposed on the basis of the research results of modern neuroscience. It attempts to process information by simulating neural network processing and memorizing information. There are three types of processing units in the network: input unit, output unit and hidden unit. The full name of BP neural network is error back propagation forward network. Its basic principle is: the network transmits a series of inputs to the hidden layer by weighting the connection weights. After the neurons in the hidden layer summarize all the inputs, they produce a certain response output through a transfer function, and then transmit them to the output layer through the next layer of connection weight. Each neuron in the output layer summarizes all inputs and then produces a response output. The output is then compared to the expected output. If they tend to be consistent or the difference is very small, it can be considered that the network has basically learned the problem. If the difference is large or not satisfactory, the error between the output of the network and the expected output will be sent back, and repeated training and learning can be carried out by adjusting the weight of each connection. Repeat training and learning, and repeat this cycle until it can produce output results that are mostly close to the real answer [10,11].

3. Results

3.1. Statistics of basic characteristics of rainfall
Based on the meteorological data from 1952 to 2019, the paper draws a linear fitting line of annual rainfall, 5-year sliding average rainfall and annual rainfall. The annual average rainfall of Guangzhou Railway Station is 1,787mm. As can be seen from the figure, the annual rainfall generally fluctuates
and the inter-annual variation shows an upward trend. Especially since the 21st century, the annual rainfall of Guangzhou Railway Station as a whole shows an increasing trend of volatility.

3.2. Variation trend and abrupt change characteristics of rainfall
The Mann-Kendall method is used to detect the variation trend and abrupt change points of rainfall at Guangzhou Station from 1952 to 2019. Given the significance level $P=0.05$, that is, $U_{0.05} = 1.96$, the calculation results are drawn as Figure 3. It can be seen from the UF curve of rainfall in Guangzhou that the variation trend of rainfall in Guangzhou before 1993 is not obvious, showing a repeated oscillation phenomenon of decreasing and increasing, while after 1993, the rainfall has an increasing trend. There are many intersections of UF and UB curves before and after 2009. During this period, the rainfall of Guangzhou station changes suddenly, and the abrupt change point is within the confidence interval, which indicates that the abrupt change is significant, and the trend of rainfall increase is more obvious.
3.3. Characteristics of multi-scale time cycle of rainfall

The multi-time scale of the rainfall time series refers to: During the evolution of rainfall, there is no real variation cycle, but its variation cycle changes with the research scale. This kind of change is generally manifested as the variation cycle of small time scale is often nested in the variation cycle of large scale. This paper selects the 68a annual rainfall data of Guangzhou Station from 1952 to 2019, and uses wavelet analysis to perform continuous wavelet transformation on the rainfall series to explore the variation characteristics of annual rainfall in Guangzhou.

a) Real part of wavelet coefficients. The contour map of the real part of the wavelet coefficients can reflect the periodic changes of the rainfall sequence at different time scales and its distribution in the time domain. It can be seen from Figure 4 that in the evolution of rainfall in Guangzhou, there are three types of periodic laws with time scales, namely below 13a, 13-20a and 20-32a, and large-scale periodic changes are nested with small-scale changes. Among them, there are 3 oscillations of alternating ample flows and dry flows on the 20-32a time scale; The specific manifestations are: relatively ample before 1962, relatively dry between 1963-1972, relatively ample between 1972-1982, relatively dry between 1983-1991, relatively ample between 1992-2000, relatively dry between 2001-2010, respectively. The isolines were not closed after 2010, indicating that they were still in a relatively ample period after 2010.

b) Wavelet variance. Wavelet variance is used to test the wavelet analysis, so as to determine the scale of the significant period corresponding to the peak value in the wavelet variance diagram is the main time scale of the sequence, that is, the main cycle. In the wavelet variance diagram of rainfall in Guangzhou, there are four obvious peaks, corresponding to 30, 15, 10 and 7a in turn. Among them, the maximum peak corresponds to the time scale of 30a, indicating that the periodic oscillation around 30a is the strongest and is the first main cycle of rainfall variation in Guangzhou (Figure 5).

c) Main cycle trend forecast. According to the results of wavelet square test, the first period wavelet coefficient map of rainfall evolution in Guangzhou is drawn, as shown in Figure 6. From the main cycle trend chart, it can be analyzed that on the time scale of 30a, the average cycle of rainfall variation is around 19a, and it has experienced about 3 ample-dry transition periods. According to Figure 6, it can be predicted that 2020 will still be in the period of "ample water", while 2021-2029 will be in the period of "dry water".

![Figure 3 Real part isoline of wavelet coefficients of annual rainfall in Guangzhou](image-url)
3.4. Long cycle forecast of rainfall

According to the results of wavelet analysis, the average period of annual rainfall variation in Guangzhou is about 19a, and there has been about 3 ample-dry transition periods from 1952 to 2019. Considering the characteristics of annual rainfall variation and periodicity in Guangzhou, this paper selects the rainfall of the last two cycles from 1952 to 2019 as the basic data of neural network training to predict the rainfall after 2019. The annual rainfall from 2000 to 2019 simulated by the neural network is compared with the actual value. The relative error is within 6.74%, and the correlation coefficient between the measured value and the simulated value is 0.992. According to the trained neural network, the rainfall in 2020 is predicted, and the predicted value is 2,628.9mm.
| Year | Measured value (mm) | Simulated value (mm) | Residual | Relative error (%) |
|------|---------------------|----------------------|----------|--------------------|
| 2001 | 2678.9              | 2678.0               | -0.9     | -0.03              |
| 2002 | 1866.7              | 1879.8               | 13.1     | 0.70               |
| 2003 | 1338.7              | 1412.7               | 74       | 5.53               |
| 2004 | 1636.5              | 1644.0               | 7.5      | 0.46               |
| 2005 | 1986.2              | 1997.7               | 11.5     | 0.58               |
| 2006 | 2175.7              | 2165.5               | -10.2    | -0.47              |
| 2007 | 1370.3              | 1462.6               | 92.3     | 6.74               |
| 2008 | 2284.0              | 2274.4               | -9.6     | -0.42              |
| 2009 | 1472.6              | 1399.1               | -73.5    | -4.99              |
| 2010 | 2353.6              | 2337.9               | -15.7    | -0.67              |
| 2011 | 1632.3              | 1634.9               | 2.6      | 0.16               |
| 2012 | 1813.9              | 1807.3               | -6.6     | -0.36              |
| 2013 | 2095.4              | 2179.1               | 83.7     | 3.99               |
| 2014 | 2234.0              | 2238.1               | 4.1      | 0.18               |
| 2015 | 2020.8              | 2020.4               | -0.4     | -0.02              |
| 2016 | 2456.8              | 2360.5               | -96.3    | -3.92              |
| 2017 | 2058.5              | 2034.0               | -24.5    | -1.19              |
| 2018 | 2070.5              | 2079.4               | 8.9      | 0.43               |
| 2019 | 2214.8              | 2142.9               | -71.9    | -3.25              |

Figure 6 Simulated statistical map of annual rainfall in Guangzhou

4. Conclusion

(1) The average annual rainfall in Guangzhou throughout the years is 1,787 mm. The annual rainfall is fluctuating overall and the interannual variation is increasing. Especially since the 21st century, the overall annual rainfall in Guangzhou has shown an increasing trend of volatility.

(2) According to the M-K analysis method, it can be known that the variation trend of rainfall in Guangzhou before 1993 was not obvious, but after 1993, the rainfall had an increasing trend. The
rainfall in Guangzhou had a sudden change before and after 2009, and the increasing trend of rainfall was more obvious.

(3) Rainfall in Guangzhou has periodic scales of 30, 15, 10, and 7a, and the 30a periodic scale has the most significant performance. On the main cycle scale of 30, the average period of rainfall variation is about 19a, and it has experienced about 3 ample-dry transition periods. The rainfall forecast value of Guangzhou in 2020 is 2,628.9mm, and it will be in "dry water" period from 2021 to 2029.

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