Analysis on Variation Characteristics of Annual Precipitation Series in Shandong Province

Jinqiu Niu¹, Jun Wang², Shengle Cao¹*, Yi Chen¹*
¹School of Civil Engineering, Shandong University, Jinan, Shandong, 250061, China
²Jinan Water Conservancy Building Survey and Design Research Institute co. LTD, Jinan, Shandong, 250100, China
cao_s@sdu.edu.cn

Abstract. Based on the data of precipitation series of 4 stations with long-term observations in Shandong Province, this paper analyzed the change characteristics of annual precipitation series, including interannual change trend, jump, period and representativeness of the series, by means of sliding average, Mann-Kendall rank correlation test, ordered clustering analysis, Fourier analysis, wavelet analysis, residual mass curve and cumulative average modulus coefficient hydrograph, etc. The results indicated that the annual precipitation series of the 4 stations have slight rising trends. The annual precipitation of Yantai Station mutated obviously in 1950. The annual precipitation series of Linqing, Huangtai Bridge and Qingdao Station have periods of 3, 10, 56 and 80 years.

1. Introduction
Shandong Province is a serious water shortage area determined by the United Nations. At the same time, the interannual change of precipitation in Shandong Province is large. Drought and flood disasters are frequent. As a result, water resources have become an important factor restricting the sustainable development of regional society and economy. Therefore, it is of great significance to analyze the change characteristics of annual precipitation series in Shandong Province and explore its change law for scientific evaluation of water resources and rational development and utilization of water resources.

At present, some scholars have analyzed and studied the change characteristics of annual precipitation series in Shandong Province. Zuo, DP et al.[1] investigated the temporal variations and spatial patterns of drought from 1960 to 2012 by means of M-K test, etc. And the results showed that the annual precipitation in Shandong Province has a dropping trend. Liu Jian et al.[2] used wavelet analysis to analyze the period change of precipitation data in Shandong Province from 1961 to 2015, and the results showed that there are 3-4, 15-16, 36-37 years change periods of annual precipitation series in Shandong Province. Wang Xu[3] studied the characteristics of the annual precipitation changes in Shandong Province from 1961 to 2015 by methods of sliding average, cumulative anomaly, M-K test, wavelet analysis, etc. And She thought that the annual precipitation of Shandong Province show a weak dropping trend, with 3-5, 7-16, 35-42 years change periods. Wang Yan, et al.[4] analyzed the representativeness of the precipitation data of Yantai and Qingdao Stations in 100 years by using the residual mass curve and other methods, and concluded that Yantai will be in the low water period for a long time at the beginning of the 21st century.

The data series used in the above analysis and research are either short or less. On the basis of previous studies, using the existing long series data, this paper synthetically adopted the methods of
sliding average, M-K test, ordered clustering analysis, Fourier analysis, wavelet analysis and residual mass curve to analyze the change characteristics of annual precipitation series, including the interannual change, the jump, period and representativeness of the series, etc. Various methods are compared and verified with each other. It is expected to further reveal the change situation of annual precipitation series in Shandong Province, so as to provide support for the correctly understanding the change law of annual precipitation series, scientific evaluation and rational development and utilization of water resources.

2. Basic data and research methods

2.1. Basic data
As there are only four precipitation stations in Shandong Province, namely Linqing, Huangtai Bridge, Qingdao and Yantai, with long series annual precipitation data. The long series measured data of the four stations are selected for this time. The series length of Linqing Station is 99 years (1918-2016), Huangtai Bridge Station is 86 years (1931-2016), Qingdao Station is 118 years (1899-2016), Yantai Station is 130 years (1887-2016). See Figure 1 for the specific location of the four stations. It can be seen from Figure 1 that Linqing Station and Huangtai Bridge Station are located inland, while Qingdao Station and Yantai Station are located along the coast.

![Figure 1. Location map of 4 rainfall stations.](image)

2.2. Research method.
In this paper, the methods of sliding average and Mann-kendall rank correlation test[5] were used to analyze the interannual variation trend of the long-term precipitation series; the ordered clustering analysis method[6] was used to analyze the mutation points of the series, and the significance of the mutation points was tested by run test and rank sum test; the Fourier level method[7] and Morlet wavelet analysis method[8] were used to analyze the period characteristics of the series; the residual mass curve [9] and cumulative average modulus coefficient hydrograph was used to analyze the representativeness of the series. The following is only a brief introduction of wavelet analysis method. Other methods will not be described in detail.

The form of Morlet wavelet function is:

$$\psi(t) = e^{i\omega_0 t} e^{-\frac{t^2}{2}}$$

(1)

For any function, its wavelet discrete transform formula as follows:

$$W_f(a,b) = |a|^{1/2} \Delta t \sum_{k=1}^{n} f(k\Delta t)\psi\left(\frac{k\Delta t - b}{a}\right)$$

(2)

Where $\omega_0$——Constant ($\omega_0 \geq 5$);
$i$——Imaginary number;
$W_f(a,b)$——Wavelet coefficients;
$a$——Scale factor, reflecting the period length of wavelet;
$b$——Time factor, reflecting the moving in time.
By integrating the square of all wavelet transform coefficients in time domain, the wavelet variance can be obtained.

\[
Var(a) = \int_{-\infty}^{\infty} |W_f(a,b)|^2 \, db
\]  

(3)

The change process of wavelet variance with scale “a” is called wavelet variance graph, through which we can know the main period of annual precipitation series.

3. Analysis of the variation characteristics of precipitation series

This section analyzed the change characteristics of annual precipitation of the 4 stations and the average value of these 4 stations, including the trend, jump, period composition and representativeness of the series.

3.1. Analysis and test of trend component

Firstly, the annual precipitation of the 4 stations and the average value of these 4 stations was analyzed by 7-point sliding average method, and drawn change curves of the series, adding trend lines. Then tested the trend by Mann-Kendall rank correlation test method (\(\alpha = 5\%\)). See Figure 2 for the change curve of annual precipitation series. See table 3-1 for M-K test results. It can be seen from Figure 2 and table 1 that:

- The annual precipitation series of the 4 stations and the average value of these 4 stations have weak rising trends, among which the rising range of Linqing and Huangtai Bridge Stations located in the inland area is slightly larger than that of Qingdao and Yantai Stations located in the coastal area; the annual precipitation series of the average value of these 4 stations have a rising range of 2.25mm/10a;
- The annual precipitation of Linqing Station and Huangtai Bridge Station experienced the process of “rise-drop-rise”, among which the annual precipitation of 1918-1964 (Linqing) and 1931-1964 (Huangtai) rose significantly;
- Qingdao and Yantai Station have experienced the change process of “drop-rise-rise-drop”, among which the rising trend was significant from 1941 to 1975, and the dropping trend was significant from 1975 to 1981 and from 2008 to 2016;
- From 1918 to 2016, the precipitation series of the average value of these 4 stations experienced a process of “rise-drop-rise-drop”, in which the precipitation rose significantly from 1918 to 1964 and dropped significantly from 2008 to 2016;
- The annual precipitation series changes of the 4 stations have good synchronization in time, most stations have experienced the change process of “rise-drop-rise-drop”. If 2 of the 4 stations are compared, the synchronization between inland 2 stations is as better as coastal 2 stations.
Figure 2. Location map of 4 rainfall stations: (a)Lingqing; (b)Huangtai Bridge; (c)Qingdao; (d)Yantai; (e)The average of the four stations.

Table 1. Mann-Kendall rank correlation test result.

| Station name | Year interval | Z   | Trend          | Station name | Year interval | Z   | Trend          |
|--------------|---------------|-----|----------------|--------------|---------------|-----|----------------|
| Linqing      | 1918-2016     | 1.15| Nonsignificant rise | 1918-1964   | 3.43          | Significant rise |
|              | 1964-1992     | -0.88| Nonsignificant drop | 1964-1989   | 0.51          | Nonsignificant drop |
|              | 1992-2016     | 1.24| Nonsignificant rise | 1989-2009   | 0.51          | Nonsignificant rise |
| Qingdao      | 1899-2016     | 0.24| Nonsignificant rise | 1887-2016   | 1.59          | Nonsignificant rise |
|              | 1899-1941     | -0.54| Nonsignificant drop | 1887-1941   | 0.86          | Nonsignificant drop |
|              | 1941-1975     | 2.75| Significant rise | 1941-1975   | 2.81          | Significant rise |
|              | 1975-1981     | -1.50| Nonsignificant drop | 1975-1981   | 2.10          | Significant drop |
|              | 1981-2007     | 1.83| Nonsignificant rise | 1981-2008   | 0.97          | Nonsignificant rise |
|              | 2007-2016     | -2.33| Significant drop | 2008-2016   | 2.40          | Significant drop |
| Yantai       | 1887-2016     | 0.84| Nonsignificant rise | 1899-1941   | -0.54          | Nonsignificant drop |
|              | 1918-1964     | 3.96| Significant rise | 1964-1981   | -0.45          | Nonsignificant drop |
|              | 1981-2008     | 1.64| Nonsignificant rise | 2008-2016   | -2.40          | Significant drop |
3.2. Analysis and test of jumping components

The ordered clustering analysis method was used to identify the mutation points of each station’s precipitation series, and the run test method and rank sum test method was used to test the mutation points ($\alpha = 5\%$). The test results are shown in table 2, and the numerical characteristics of the series before and after the mutation points of each station are shown in table 3.

| Station name   | Mutation year | Run test     | Rank sum test |
|----------------|---------------|--------------|---------------|
| LinQing        | 1934          | Significant  | Nonsignificant|
| Huangtai Bridge| 1944          | Nonsignificant| Nonsignificant|
| Qingdao        | 1996          | Nonsignificant| Nonsignificant|
| Yantai         | 1950          | Nonsignificant| Significant   |

Table 3. Numerical characteristics before and after mutation point of series.

| Station name | Mean value | Variance | Series length (year) | Mean value | Variance | Series length (year) | Mean value | Variance |
|--------------|------------|----------|----------------------|------------|----------|----------------------|------------|----------|
| LinQing      | 534.4      | 27251    | 17                   | 446.3      | 15893    | 82                   | 552.7      | 27662    |
| Huangtai Bridge | 662.9 | 33196    | 14                   | 588.4      | 21048    | 72                   | 677.4      | 34268    |
| Qingdao      | 673.5      | 39522    | 98                   | 672.4      | 38350    | 20                   | 679.1      | 45228    |
| Yantai       | 653.0      | 24484    | 64                   | 613.0      | 21231    | 66                   | 691.8      | 24578    |

It can be seen from table 2 and table 3 that:

- The length of the series before and after the mutation point in Yantai Station is not much different, and the representativeness is good. The mutation passed the rank sum test. The mean value and variance of precipitation series after the mutation point are significantly higher than that before the mutation point, so 1950 should be a mutation year of the precipitation series at Yantai Station;
- The mean value and variance of the precipitation series after the mutation points of LinQing and Huangtai Bridge Station are also significantly higher than that before the mutation points, and the mutation point of LinQing Station has passed the run test. However, due to the great difference between the series length before and after the mutation points, the series before the mutation points may be just in the low water period, so the reason for determining the jump component is not enough;
- There is no jumping component in Qingdao Station.

3.3. Analysis of period component

Fourier analysis and wavelet analysis were used to analyze the periods of annual precipitation series of the 4 stations and the average value of these 4 stations. The specific processes are as follows.

3.3.1. Fourier analysis method. Take the significance level $\alpha = 5\%$, and the analysis results are shown in table 4. It can be seen from table 4 that the annual precipitation series of the 4 stations and the average of these 4 stations all have a period of 3 years, and most of them have periods of about 10 years.

| Station name | LinQing | Huangtai Bridge | Qingdao | Yantai | Average value of the 4 stations |
|--------------|---------|-----------------|---------|--------|---------------------------------|
| Period (year) | 10,3    | 14,9,3          | 12,7,4,3| 6,3    | 12,3                            |

3.3.2. Wavelet analysis method. Morlet wavelet analysis method was used to calculate wavelet variance and draw wavelet variance graph, as shown in Figure 3. From figure 3, we can see the periods of annual
precipitation series of each station, as shown in table 5. Because of the research series are long, the short periods are not obvious in the wavelet variance map, and the short period has been studied in the Fourier analysis, so the main research of this wavelet analysis is the longer period.

It can be seen from figure 3 and table 5 that:
- Linqing, Huangtai bridge and Qingdao Station all have obvious periods of 56 and 80 years;
- There are 26, 68 and 95 years’ periods in Yantai Station;
- The variation period of the average value of 4 stations is inconsistent with that of each station, which may be caused by the inconsistency between the period of Yantai Station and the other 3 stations.

Table 5. Period results of wavelet analysis.

| Station name   | Linqing      | Huangtai Bridge | Qingdao   | Yantai   | Average value of the 4 stations |
|----------------|--------------|-----------------|-----------|----------|---------------------------------|
| Period(year)   | 14,35,56,80  | 19,56,79        | 19,56,78  | 26,68,95 | 19,26,36,68,92                  |

Figure 3. Chart of annual precipitation wavelet variance: (a)Linqing; (b)Huangtai Bridge; (c)Qingdao; (d)Yantai; (e)The average of the four stations.

Combined the results of Fourier and wavelet analysis, the main conclusions are as follows:
- There are obvious differences between Yantai Station and other three stations;
- The three stations of Linqing, Huangtai bridge and Qingdao have periods of 3, 10, 56 and 80 years, while Yantai Station have periods of 3, 6, 26, 68 and 95 years.

3.4. Analysis of period component

The representativeness of the series was analyzed by residual mass curve and cumulative average modulus coefficient hydrograph.

3.4.1. Residual mass curve. Take the year as abscissa and the residual mass value “$\sum(K_i - 1)$” as ordinate to draw the annual precipitation residual mass curve of the 4 stations and the average value of these 4 stations, as shown in Figure 4. We can see from 4 that:
- The annual precipitation of the 4 stations have obvious alternation of wet and dry, and the changes are synchronous;
- The residual mass curves of Linqing, Qingdao, Yantai and the average value of the 4 stations have gone through the process of “drop-rise-drop”. It can be seen that the series periods are about 80 years, which is basically consistent with wavelet analysis;
- The residual mass curve of Huangtai Bridge Station fluctuates greatly, the period component is not obvious, so its series period cannot be inferred.
3.4.2. Cumulative average modulus coefficient hydrograph. Draw the curve with the year as abscissa and the average value of modulus coefficient as ordinate, as shown in Figure 5. From figure 5, it can be seen that the time required for the cumulative average modulus coefficient of the 4 stations and the average value of these 4 stations to reach stabilization is about 80 years, so the representative period of the series is about 80 years.

It can be seen from above that the analysis results of cumulative average hydrograph, residual mass curve and wavelet analysis method are consistent basically. Therefore, the analysis conclusion is basically credible.

4. Conclusion

- The precipitation series of Linqing, Huangtai Bridge, Qingdao, Yantai Station and the average value of these 4 stations all have a weak rising trend. Most stations have experienced the change process of “rise-drop-rise-drop”, among which, in 1918-1964 (Linqing), 1931-1964 (Huangtai), 1941-1975 (Qingdao, Yantai), increased significantly, in 1975-1981, 2008-2016 (Qingdao, Yantai), decreased significantly;
- The annual precipitation series of the 4 stations have good synchronization in time. Compared the 4 stations in pairs, the synchronization between inland 2 stations is as better as coastal 2 stations;
- In 1950, the precipitation series of Yantai Station had a mutation, and there was obvious jump component. The other three stations have no significant jumping components;
- The periods of Yantai Station and the other three stations are obviously different. The precipitation series of the other three stations have periods of about 3, 10, 56, 80 years, while Yantai station have periods of 3, 6, 26, 68 and 95 years.

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