Analysis of Spatial-temporal Distribution Characteristics of Precipitation in Shandong Province from 1961 to 2017

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Abstract: According to the precipitation data of Shandong Province, the trend of precipitation change in Shandong Province was firstly analyzed through the climate trend rate, and then the abrupt change point of precipitation was detected by the Mann-Kendall test, sliding t test and other methods, and the periodic features were extracted by wavelet analysis. The spatial characteristics of precipitation are analyzed by kriging interpolation method in ArcGIS. The results showed that the interannual precipitation in Shandong Province decreased in summer and autumn, and increased slightly in spring and winter. Through multiple methods, we have identified the interannual, seasonal abrupt points. Then, we found the first, second and third periods of interannual precipitation. In terms of space, the annual precipitation gradually decreases from the southeast coast to the northwest inland; the annual precipitation in each region of Shandong Province is basically reduced to a different extent, and the southeast coastal region has a larger reduction than the northwest inland region.

1. Introduction
Precipitation is a key link in the water cycle process, and an important factor affecting the amount of water resources in this region. Its changes affect every aspect of our production and life. At the same time, precipitation directly affects the runoff of surface rivers. The study on the change of precipitation can provide reference for the prediction and prevention of flood disaster and guarantee the development of agriculture and food security. Therefore, it is of great significance to study the temporal and spatial distribution of rainfall.

In recent years, based on the precipitation data of meteorological stations, many scholars have fully analyzed the precipitation in different river basins and regions. Precipitation of summer in Shandong Province shows a decreasing trend, and drought occurs frequently in spring. "Water shortage", "frequent drought" and "uneven precipitation" are important water conditions in Shandong Province. The shortage of water resources and uneven distribution makes the sustainable development of Shandong Province restrained. At present, there are relatively few studies on the overall precipitation change in Shandong Province, so it is necessary to further analyze the precipitation change and spatial and temporal distribution characteristics in Shandong Province in detail.

2. Overview of Shandong Province and Data Sources
Shandong Province, located in the east coast of China, the end of the Yellow River region, mid-latitude
zone, belong to a warm temperate continental monsoon climate. Precipitation is concentrated in summer, hot rain in the same season, short spring and autumn, long winter and summer. The average annual temperature is about 11 °C ~ 14 °C, and the average annual precipitation is generally between 430 mm ~ 950 mm. According to topography, Shandong Province can be divided into two regions: the peninsula and the west, the eastern peninsula is a hilly region with gentle terrain, while the western and northern regions are plains formed by the alluvial Yellow River. The average altitude is lower than 50 meters, among which the Yellow River delta is the lowest.

The data used in this paper come from the monthly data set of Chinese surface climate data from China meteorological data network. The data set has passed the extremum test and time consistency test, and the data are reliable. In the downloaded data of 29 stations, I deleted the stations with a large number of missing values. For the few stations that did not have the monthly value data, the multi-year average value of the month was used to replace, and there were 23 sites in total (Figure 1).

Figure 1. distribution of meteorological stations in Shandong province

3. Research Methods

3.1 Trend Analysis
Climate trend rate can analyze the change trend of climate elements[7]. This method is to establish a linear regression equation with one variable between time and precipitation:

\[ Y_i = a + bt_i \quad (i = 1,2,\ldots,n) \]  

Where, \( Y_i \) is a climate variable with sample size of \( n \), such as precipitation; \( a \): the regression constant; \( b \): the regression coefficient; \( a \) and \( b \) are estimated by the least square method. Among them, 10b is the climate trend rate, mm/10a. When \( b > 0 \), Yi shows an upward trend with the passage of time \( t_i \). When \( b < 0 \), Yi decreases.

The core idea of moving average is to calculate the average value of data in time series by increasing and subtracting successively, and obtain a new set of time series values, which can effectively reduce the error caused by accidental events, analyze its change trend, and make prediction.

3.2 Mutations in the inspection
The Mann-Kendall test is a non-parametric test method recommended by FAO for sequence analysis[8]. This test does not require samples to follow specific distribution characteristics, and can well exclude the influence of a small number of outliers. It is applicable to some hydrological and meteorological sequences with non-normal distribution. Sliding t test is to determine whether the average value of two sub-sequences in the sequence has a significant change. If the change exceeds the given significance level, the point can be judged as a mutation point. The Cramer test is similar to the sliding t test in principle, except that the Cramer test is used to determine the mutation point by whether there is a significant difference between the average value of the whole sequence and one of the sub-sequences. Yamamoto test discusses the abrupt change points from the perspective of climate
information and climate noise. When the signal-to-noise ratio sequence exceeds the significance level, the abrupt change occurs[9].

4. Results and Analysis

4.1 Analysis of Precipitation Time Variation

We draw the interannual and seasonal process lines with the monthly precipitation of 57 years in Shandong Province from 1961 to 2017 (Figure 2). From Figure 2, it can be seen that the precipitation variation range of Shandong Province is in order from large to small: interannual, summer, autumn, spring and winter. According to Figure 2(a), the annual precipitation in Shandong Province is between 437.73 mm and 1196.76 mm. The average precipitation is about 696.45 mm, the coefficient of variation is 0.20, and the annual precipitation difference is about 2.73 times. The climate trend rate is -17.48mm/10a, which means the annual precipitation is decreasing. The 5-point moving average indicates that the precipitation fluctuated greatly from 1960s to early 1980s and after the 21st century, the middle part was stable and the two ends fluctuated greatly.

According to the spring precipitation in Figure 2(b), the precipitation in spring (march-to-may) is about 31.28mm ~ 201.29mm, the average precipitation in spring is about 104.55mm, the coefficient of variation is 0.36, and the extreme precipitation difference in spring is about 6.44 times. The climate trend rate was 0.47mm/10a, indicating a slight upward trend in spring precipitation. By observing the 5-point moving average, it can be concluded that the fluctuation of spring precipitation is not big, but after entering the 21st century, the fluctuation tends to increase.

According to Figure 2(c), the precipitation in summer (June to August) ranges from 220.09mm to 704.71mm, the average precipitation in summer is about 432.85mm, the coefficient of variation is 0.24, and the extreme precipitation difference in summer is about 3.2 times. The precipitation in summer showed a decreasing trend. According to the 5-point moving average, there were two peaks in 1970a ~ 1975a and 2005a ~ 2010a, while the latter peak was slightly smaller than the prior peak.

According to the precipitation in autumn in Figure 2(d), the precipitation in autumn (September to November) ranges from 34.97mm to 276.89mm, the average precipitation in autumn is about 129.16mm, the coefficient of variation is 0.43, and the extreme precipitation difference in autumn is about 7.92 times. The precipitation in autumn showed a downward trend, and the climate trend rate was -6.48mm/10a. According to the observation of the 5-point moving average, the autumn precipitation has a certain periodic fluctuation, and the crest gradually decreases.

According to the precipitation in winter in Figure 2(e), the precipitation in winter (December to February of the next year) ranges from 3.45mm to 66.29mm, the average precipitation in winter is about 29.89mm, the coefficient of variation is 0.46, and the extreme precipitation difference in winter
Figure 2. Interannual and seasonal variations of precipitation in Shandong Province from 1961 to 2017 is about 19.23 times. The winter climate trend rate was 0.37mm/10a, and the winter precipitation showed a slight upward trend. According to the 5-point moving average, a maximum valley peak appeared around 1993, and the sequence before valley peak generally showed an upward trend, while after valley peak generally showed a downward trend.

4.2 Mutation Test
The Mann-Kendall test was used to analyze the interannual and seasonal precipitation from 1961 to 2017(Figure 3). Significance level $p=0.05$. In the analysis of annual precipitation, the UF and UB curves had three intersections, among which only the abrupt transition point exceeded the critical point in 2002a ~ 2003a. If there are multiple intersection points in the Mann-Kendall test, they are not necessarily all mutation points and may be false mutation points. Pettitt test detected that 2002a was a
mutation point, while sliding t test, Cramer test and Yamamoto test detected that 1976a and 2002a were mutation points. The interannual abrupt changes were finally determined in 1976a and 2002a. Similarly, the spring mutation point was 2009a, the summer mutation point was 1978a, the autumn mutation point was 1975a and 2010a, and the winter mutation point was 1979a and 1988a.

4.3 Periodic Analysis

The precipitation in Shandong Province was analyzed by using Matlab wave toolbox. According to Contour map of the wavelet coefficients (Figure 4), it can be concluded that there are two obvious oscillation periods in Shandong Province. Among them, the variation rules of precipitation scales 4a ~ 8a and 20a ~ 25a are all regional, and the corresponding central scales are 4a, 8a and 22a. According to the unclosed contour after 2017a, it can be concluded that the annual precipitation in Shandong Province will continue to decrease. According to difference of wavelet square in precipitation (Figure 5), annual precipitation in Shandong Province has three periods of 4a, 8a and 22a. Among them, the largest value of the variance is 22a, that is, the first main period, and 8a and 4a are secondary periods.

According to 22a and 8a feature time scale wavelet real part process lines (Figure 6). it can be concluded that the precipitation variation in different time scales has the characteristics of the average period and the variation between abundant and dry. In the 22a time scale, the average period of precipitation change is about 14 years, and it has experienced about 4 periods of abundant and dry transition. In the 8a time scale, the average period of precipitation change is approximately 5 years, and it has experienced about 11 periods of abundance - drought transition.
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4.4 Analysis of Precipitation Spatial Change

According to the spatial distribution of annual average precipitation in Shandong Province (Figure 7), precipitation is more in the southeast than in the northwest. The precipitation in the eastern coastal areas is higher than that in the western and northern regions, except for Mount Tai. The highest precipitation area is in Mount Tai, where the annual precipitation is more than 1000mm, which is more than 300mm higher than the average annual precipitation of the whole Shandong Province. The low precipitation is concentrated in the northwest of Shandong Province, about 550mm-620mm, which is more than 80mm-150mm lower than the average annual precipitation of Shandong Province. By comparing the distribution diagram of seasonal precipitation, it can be observed that the distribution pattern of precipitation in spring, summer, autumn and winter is basically the same as that of annual precipitation. The difference lies in the difference of precipitation amount. Therefore, the distribution diagram of seasonal precipitation is omitted.

The annual and seasonal precipitation trends in Shandong Province was plotted by the annual and seasonal climate trend rates of each station (Figure 8). The analysis of Figure 8 (a) shows that the precipitation in Shandong Province basically presents a downward trend, with a significant downward trend in the southeast coastal areas and a slow decline in the northwest inland areas. Except for Jinan, which showed a slight upward trend of 1.92mm/10a, all other regions showed a downward trend of varying degrees. The most obvious decline trend is from Rizhao to Chengshantou area, with a decline range from -28.92mm/10a to -37.90mm/10a. Figure 8 (b) in the middle of spring, most areas showed a slight upward trend, and the western region was more than the eastern region. The largest upward trend was in Jinan (6.76mm/10a), while the downward trend appeared in the east of Qingdao, Yantai, Weifang City and southwest of Heze, with the highest downward trend reaching -3.00mm/10a. Figure 8 (c) in summer, it is found that the variation trend of summer and the variation trend of annual precipitation have a similar distribution pattern. The precipitation in summer presents a downward trend, and the downward trend of southeast coastal region (greater than -16mm/10a) is higher than that of northwest inland region (less than -10mm/10a). In Figure 8 (d) in the autumn, with the exception of Texas north-west, the south of the south of Heze, Jining has a slight upward trend, the rest of the region is on the decline, the Midwest falling trend bigger parts of southwest Liaocheng, Taian City and Zibo, drop of 8.36 mm / 10 a ~ 11.56 mm / 10 a), the decline was most pronounced in the east area is located in the east of Yantai and Weifang City (11.09 mm / 10 a) (greater than 10-12 mm/a). Figure 8 (e) in winter, the east of Dongying, the east of Zibo and the west of Weifang City showed a slight downward trend, while most of the other regions showed a slight upward trend.

5. Conclusion

Based on the monthly precipitation data of 23 stations in Shandong Province for nearly 57 years, a series of methods were used to analyze the time and space aspects, and the following conclusions were drawn:
(1) the annual precipitation in Shandong Province showed an overall downward trend, and its climate trend rate was -17.48 mm/10a. From the seasonal analysis, the precipitation in spring and winter shows a slight upward trend. In summer, the change rate was -11.84 mm/10a, and the decline trend was not obvious in autumn. The change of summer precipitation contributes the most to the annual precipitation.

(2) according to Mann-Kendall test, sliding t test and other methods, the annual precipitation abrupt change point is 1976a and 2002a, spring abrupt change point is 2009a, summer abrupt change point is 1978a, autumn abrupt change point is 1975a and 2010a, and winter abrupt change point is 1979a and 1988a.

(3) the first cycle of annual precipitation is 22a, and the second cycle is 8a and 4a.

(4) precipitation is concentrated in Taian City region, with annual precipitation of more than 1000mm. Annual precipitation gradually decreases from the southeast coast to the northwest inland direction. The annual precipitation in Shandong Province basically presents a downward trend, with a significant downward trend in the southeast coastal region, but a slow decline in the northwest inland region. In the spring, summer and autumn precipitation variation trend, the southeast coastal region and Jiaozhou peninsula region mostly show a downward trend, while the northwest inland region shows a small change trend. Winter precipitation in the south of Shandong Province tends to rise while that in the north tends to fall.

Figure 7. Spatial distribution of multi-year average precipitation in Shandong Province from 1961 to 2017
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Figure 8. Trends of interannual and seasonal precipitation in Shandong Province from 1961 to 2017