Precipitation Sequence Analysis of Representative Stations in Shandong Province from 1956 to 2016

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Abstract. Based on the monthly precipitation observation data of 17 hydrological representative stations in Shandong Province from 1956 to 2016, Moving-average method, Mann-Kendall test method, precipitation concentration degree and concentration period were used to comprehensively study the distribution characteristics of precipitation in Shandong. The results show that in terms of inter-annual changes, the annual precipitation in Shandong province shows a declining trend, and the precipitation in coastal areas is generally larger than that in inland areas. Judging from the annual distribution, the precipitation in Shandong during the flood season shows a downward trend, and the non-flood season precipitation shows an upward trend. From 1956 to 2016, the precipitation concentration degree and the precipitation concentration period in Shandong Province showed a weak decline.

1. Introduction
Precipitation is an important factor in the hydrologic cycle, its change process reflects regional climate change and determines the characteristics and evolution direction of regional water resources to a certain extent [1]. Therefore, it is of great guiding significance to study and grasp the change characteristics and trend of precipitation sequence for the implementation of water resources planning and management in the region and the guarantee of industrial and agricultural production [2].

As a major province of agriculture, Shandong province has a total amount of 30.81 billion m³ of local water resources, but the per capita water resource is only 315 m³/a, which is barely 1/24 of the world level. And the precipitation annual distribution in Shandong is very uneven, which is concentrated in the flood season. To date, there are numerous studies that analyze rainfall variability in Shandong province at different temporal scales (from daily to annual) in China. Huanghao et al. [3] used the precipitation concentration index Q to analyze the daily precipitation data of 22 weather stations in Shandong province during the flood season from 1981 to 2017 (June to September). Xuzehua et al. [4] studied the daily precipitation data of 18 meteorological stations in Shandong province from 1981 to 2010, and the analysis showed that the precipitation change in Shandong region had similar oscillation cycles with the southern oscillation and the East Asian summer monsoon. Xuzongxue et al. [5] analyze the long-term trend of precipitation in 15 stations in Shandong province from 1958 to 1998, and the results showed that the average annual precipitation in Shandong province during this period showed a downward trend, with the largest average decline in the southeast coast. Most of the existing studies are based on short precipitation sequences less than 40 years old and lack comprehensive analysis.

In this paper, based on the monthly precipitation data from 1956 to 2016 in Shandong province,
trend change of precipitation series and the uniformity of precipitation distribution are evaluated to provide a reasonable basis for the change of water resources in Shandong province.

2. Study area and data
In this study, the monthly precipitation observation data from 17 representative stations in Shandong province from 1956 to 2016 is provided by the bureau of hydrology of Shandong province. Which was weighted by Tyson polygon method. The distribution of representative sites is shown in figure 1.

3. Research Method
In this study, linear trend estimation, sliding average method and Mann-Kendall test (M-K test) [6-8] are used to analyze the trend change of precipitation series, and coefficient of variation method, precipitation concentration degree and concentration period [9,10] are used to evaluate the uniformity of precipitation distribution. The following is only a brief introduction of precipitation concentration degree and concentration period. Other methods will not be described in detail.

Concentration degree and concentration period are used to reflect the concentration degree and center of gravity of annual precipitation distribution (annual precipitation is concentrated at a certain time). The monthly precipitation in 12 months of a year is regarded as a vector, the monthly precipitation is taken as the module of the monthly precipitation vector, the month is taken as the direction of the vector, and is represented by the direction of the circle (the degree of circle 360° is taken as 365 days of the year, and 1 day is equivalent to 0.9863°). Sum the precipitation vector of each month in a year, the ratio of the vector model to the annual precipitation is annual precipitation concentration degree (PCD), and the vector direction is annual precipitation concentration period (PCP). The calculation formula is as follows:

\[
\begin{align*}
R_x &= \sum_{j=1}^{12} r_j \sin \theta_j \\
R_y &= \sum_{j=1}^{12} r_j \cos \theta_j \\
PCD &= \sqrt{R_x^2 + R_y^2} / R_i \\
PCP &= \text{arctan}(R_x / R_y)
\end{align*}
\]

Where \( r_j \) = Monthly precipitation for month j in year i, \( \theta_j \) = Azimuth Angle corresponding to month j (take the azimuth Angle corresponding to the middle day of each month, such as 15.29° corresponding to January), \( R_i \) = The annual precipitation in the year i.

If the precipitation in a given year is concentrated in a single month, the ratio of the synthetic vector to the annual precipitation is 1, and PCD is the maximum. If the precipitation is the same in all months of the year, the resultant vector is 0 and PCD is a minimum. It can be seen that the value of PCD is between 0 and 1, and the closer it is to 1, the more concentrated the precipitation is and the more uneven the distribution of precipitation is in a year. The closer to 0, the less concentrated the precipitation, the more evenly distributed the year. PCP calculates the azimuth of the synthetic vector, reflecting the time in a year when precipitation is concentrated.
4. Interannual changes of precipitation

4.1. Interannual distribution of precipitation

According to the available data, the average and the variation coefficient of annual precipitation from 1956–2016 in Shandong province and each representation station can be calculated. The annual precipitation of Shandong province fluctuated between 419.1 and 1210.2mm, the maximum appeared in 1964, and the minimum appeared in 2002, the average annual precipitation was 694.4mm, the variation coefficient was 0.20. Among 17 stations, Rizhao station has the highest average annual precipitation (875.8mm), Linqing station has the lowest average annual precipitation (542.1mm). The interannual precipitation variation coefficient of each station is between 0.23 and 0.32.

Figure 2 shows the spatial distribution of average annual precipitation in Shandong province from 1956 to 2016. It can be seen that the annual average precipitation in Shandong province gradually decreases from southeast to northwest. The annual average precipitation in Southeast Shandong such as Linyi, Rizhao and Weihai is over 800 mm; while in western Shandong and Northern Shandong, the annual average precipitation is relatively small, which is below 600mm.

![Figure 2. The annual mean precipitation map in Shandong Province](image)

4.2. The analysis of annual precipitation variation trend

Precipitation changing curve of Shandong province and representative stations was drawn and the 5 moving average (years) was manipulated, at the same time equation of annual precipitation change over time was fitted. The precipitation changing curve of Shandong Province and three representative stations—Rizhao station, Yanma station and Haiyang station is shown in figure 3, the other representative stations are no longer listed.
Figure 3. The precipitation changing curve of Shandong Province and other stations
(a) Shandong Province  (b) Rizhao Station  (c) Yanma Station  (d) Haiyang Station

From figure 3, it can be seen that:

- the annual precipitation in Shandong province decreased at an average rate of -1.46mm/a from 1956 to 2016, while that in Rizhao, Yanma and Haiyang station decreased at an average rate of -2.87mm/a, -2.74mm/a and -2.97mm/a.

- Among 17 representative stations, the annual precipitation series of 14 stations showed a downward trend, the decline rate of Haiyang station was the largest, -2.97mm/a. The annual precipitation series of 3 representative stations, including Huangqian, Linwen and Baojizha, showed an upward trend, with the maximum upward rate of 0.24mm/a at Huangqian station.

The annual precipitation sequence of Shandong province and 17 representative stations from 1956 to 2016 was analyzed by M-K test, and the results are shown in table 1.

| Number | Station  | Z       | up/down | Number | Station  | Z       | up/down |
|--------|----------|---------|---------|--------|----------|---------|---------|
| 1      | Linqing  | -0.23   | down    | 10     | Baocun   | -0.64   | down    |
| 2      | Sinsvizha| -0.96   | down    | 11     | Haiyang  | -1.84   | down    |
| 3      | Baojizha | 0.22    | up      | 12     | Andi     | -1.49   | down    |
| 4      | Huangqian| -0.17   | down    | 13     | Linyi    | -0.66   | down    |
| 5      | Linwen   | 0.43    | up      | 14     | Houying  | -1.10   | down    |
| 6      | Yangjiaogou| -0.87 | down   | 15     | Ysnma    | -1.88   | down    |
| 7      | Xiashan  | -0.88   | down    | 16     | Huangsi  | -1.28   | down    |
| 8      | Nancun   | -1.29   | down    | 17     | Rizhao   | -2.18   | down    |
| 9      | Menlou   | -1.80   | down    |        | Shandong province | -1.50 | down |

It can be seen from table 1 that annual precipitation in Shandong province has a downward trend. Among 17 representative stations, the annual precipitation sequences of 15 stations have a downward trend, in which Rizhao station has a significant decline, while 2 stations — Baojizha station, Linwen station have a upward trend.
5. **Annual distribution of precipitation**

5.1. *Precipitation distribution in month and flood season*

The distribution of average monthly precipitation in Shandong province is shown in figure 4. It can be seen that the precipitation is concentrated from May to September, with the largest precipitation in July, followed by August and June, and the smallest in January. The average precipitation in the flood season (June to September) is 505.8mm, accounting for 72.83% of the annual precipitation.

![Figure 4](image4.png)

**Figure 4.** The perennial average monthly precipitation distribution in Shandong Province

M-K test is used to test the trend component of the monthly rainfall sequence of Shandong province and representative stations. The month precipitation sequence of February and May has obvious rising trend, with 16 representative stations in February and 17 representative stations in May having rising trend; the month precipitation sequence of January, March, April, July and October has obvious downward trend, with 16 representative stations in January, 17 representative stations in March, 16 representative stations in April, 15 representative stations in July and 17 representative stations in October having downward trend; there was no obvious change trend in other months.

Flood is usually caused by continuous rainfall or several rainstorms in the flood season. Therefore, the analysis of precipitation in the flood season plays an important role. The curve of precipitation change in flood season and non-flood season of Shandong province can be seen in figure 5.

![Figure 5](image5.png)

**Figure 5.** The precipitation changing curve of flood season and non-flood season in Shandong

As can be seen from figure 5, during the period from 1956 to 2016, precipitation in the flood season of Shandong province decreased at an average rate of -1.53mm /a, which was faster than the average annual precipitation of -1.46mm /a, while precipitation in the non-flood season increased at an average rate of 0.064mm/a, indicating that the proportion of precipitation in the flood season of Shandong province had a decreasing trend.

5.2. *Precipitation concentration degree and concentration period*

The precipitation concentration degree (PCD) and precipitation concentration period (PCP) changing curve in Shandong province from 1956 to 2016 is shown in figure 6. It can be seen that PCD in
Shandong province decreased slowly at an average rate of -0.004/10a from 1956 to 2016. From the five-year sliding average curve, PCD showed a general trend of fluctuation and decline from the mid-1950s to the late 1980s, a trend of fluctuation and increase in the early 1990s, and a trend of fluctuation and decline in PCD after 2006. The PCP of Shandong province showed a downward trend at -0.22°/10a from 1956 to 2016. From the 5-year sliding average curve, PCP showed a downward trend of fluctuation.

The calculation results of PCD and PCP multi-year mean value, variation coefficient, trend component test value Z of Shandong province and representative stations are shown in Table 2.

| Station     | PCD multi-year mean value | PCD Cv | PCD Z | up/down | PCP multi-year mean value | PCP Cv | PCP Z | up/down |
|-------------|----------------------------|--------|-------|---------|----------------------------|--------|-------|---------|
| Linqing     | 0.62                       | 0.16   | -0.40 | down    | 201.4                      | 0.068  | -0.98 | down    |
| Sinvsizha   | 0.66                       | 0.13   | -0.98 | down    | 203.3                      | 0.059  | -0.55 | down    |
| Baojizha    | 0.65                       | 0.14   | 0.95  | up      | 202.8                      | 0.062  | -0.30 | down    |
| Huangqian   | 0.65                       | 0.15   | 0.40  | up      | 203.1                      | 0.049  | -1.16 | down    |
| Linwen      | 0.62                       | 0.15   | -0.11 | down    | 201.6                      | 0.058  | -0.07 | down    |
| Yangjiaogou | 0.61                       | 0.17   | -1.57 | down    | 203.9                      | 0.067  | -1.25 | down    |
| Xiashan     | 0.58                       | 0.16   | -0.24 | down    | 202.8                      | 0.071  | -0.28 | down    |
| Nancun      | 0.60                       | 0.14   | 0.84  | up      | 205.5                      | 0.067  | 0.28  | up      |
| Menlou      | 0.56                       | 0.19   | -0.83 | down    | 208.3                      | 0.072  | -2.13 | down    |
| Baocun      | 0.56                       | 0.19   | -0.65 | down    | 209.3                      | 0.073  | -1.62 | down    |
| Haiyang     | 0.60                       | 0.17   | -1.21 | down    | 203.5                      | 0.062  | -1.28 | down    |
| Andi        | 0.61                       | 0.14   | -0.79 | down    | 201.2                      | 0.059  | 0.75  | up      |
| Linyi       | 0.60                       | 0.14   | -0.59 | down    | 200.8                      | 0.067  | 0.50  | up      |
| Houying     | 0.59                       | 0.17   | -0.42 | down    | 202.2                      | 0.072  | 0.19  | up      |
| Yamna       | 0.61                       | 0.15   | -0.15 | down    | 200.6                      | 0.069  | 0.59  | up      |
| Huangsi     | 0.56                       | 0.17   | -0.26 | down    | 202.4                      | 0.081  | 0.40  | up      |
| Rizhao      | 0.59                       | 0.16   | -1.44 | down    | 204.8                      | 0.072  | 1.06  | up      |
| Shandong province | 0.60              | 0.12   | -0.47 | down    | 203.4                      | 0.05   | -0.42 | down    |

From Table 2, it can be analysed that:
- the PCD multi-year mean value in Shandong province from 1956 to 2016 was 0.60, indicating that the distribution of precipitation within a year was relatively concentrated, the value of 17 stations was between 0.56 ~ 0.66.
- PCD in Shandong province and 14 representative stations showed a downward trend, indicating that the annual distribution of precipitation in most areas of Shandong province tends to be even, which is consistent with the conclusion obtained in section 5.1.
The multi-year mean value of PCP in Shandong province from 1956 to 2016 was 203.4, that is, in late July, and the fluctuation range was between 177.0 and 223.4, that is, from late June to early August.

The multi-annual mean value of PCP of 17 representative stations fluctuates from 201 to 209, that is, in late July. The variation coefficient fluctuates between 0.04 and 0.08, indicating that the PCP has not changed much over the years. The PCP in Shandong province and 10 representative stations showed a downward trend, that is, the precipitation concentration time moved forward, among which the PCP of Menlou station significantly decreased. The PCP of 7 representative stations had a rising trend, that is, the precipitation concentration time moves behind.

6. Conclusions
According to the above analysis of this paper, the following conclusions can be obtained from 1956 to 2016:

- The annual precipitation of Shandong province from 1956 to 2016 fluctuated between 419.1 and 1210.2mm, and the average annual precipitation decreased gradually from southeast to northwest in Shandong.
- There is a downward trend in annual precipitation of Shandong province. Among the 17 representative stations, annual precipitation of 15 has a downward trend (a significant decline in Rizhao station), while 2 (Baojizha and Linwen station) have downward trends.
- Precipitation in the flood season in Shandong province tends to decrease, while in the non-flood season tends to increase. The increase of precipitation in February and May has a great contribution to the increase of precipitation in non-flood season, while the decrease of precipitation in July contributes to the decline of precipitation in flood season.
- PCD in Shandong province shows a downward trend. Among the 17 representative stations, 14 have a downward trend, while 3 have an upward trend. PCP in Shandong province and 10 representative stations shows a downward trend, that is, the precipitation concentration period moves forward, while PCP of 7 representative stations such as Nancun station shows an upward trend, that is, the precipitation concentration period moves backward.

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