Evolution characteristics research on summer-autumn consistent drought of Poyang Lake based on the copula in the changing environment

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Abstract. The precipitation series is the main data to calculate the parameters and the frequency of drought, aim to the less considering with the inconsistency of precipitation series in study of drought research under the changing environment, and the less reasearch on the drought evolution characteristics within the basin before and after the hydrological alteration, the hydrological alteration diagnosis system was used to diagnose the summer and fall precipitation series of Yichun, Nanchang etc. and 9 meteorological station in total within the basin of Poyang lake. Based on the hydrological alteration results and considering the Copula function, the percentage of precipitation anomaly (Pa) was taken as the drought index to calculate the percentage of summer-fall consistent drought of meteorological stations. The results show that, the alteration of precipitation series in summer was obvious at Poyang lake, comparing with the period before the alteration, the percentage of summer-fall consistent drought of Poyang Lake is decreasing, that means the recurrence period of summer-fall consistent drought becomes longer, the main reason that induce the much more serious drought in the Poyang Lake is the factor of water expenditure.

Key words: copula function; changing environment; inconsistency; Poyang lake

1. Research background
The special functions of regulating regional climate, providing drinking water and food, maintaining regional ecosystem balance and breeding biodiversity, etc. [1], lakes become the important places for human survival, and the important parts of the terrestrial hydrosphere. However, in recent years, due to the impact of climate change and human activities, the temporal and spatial distribution of water resources in the lake basin has changed, the abnormal phenomenon such as water storage reduced rapidly, the extremely low water level, etc. is increasing [2]. Compared with historical statistical data from the year of 2000, the return period of drought at different places appeared obvious inconsistency problem. Taking Poyang Lake Basin as an example [3], from the year of 2003, the occurrence of the low water level of Poyang Lake has been greatly advanced, the duration of the low water period has been significantly prolonged, and the extreme low water level has been significantly reduced, which causes the difficulty of water intake, the shrinkage of wetland, the sharp decline of lake water quality and the reduction of lake water ecological function, has a great impact on the regional social and economic development and ecological environment protection.
Many scholars have studied the characteristics of drought evolution in Poyang Lake Basin. Based on the precipitation and water level, Min [4, 5] analyzed the characteristics of drought evolution of Poyang Lake, and put forward countermeasures to deal with drought. Min et al. [6] used Z index to analyze the meteorological drought in Poyang Lake Basin, and pointed out that the scope and intensity of drought was increasing since 2000. Based on the SPI index, Hong [7] analyzed the temporal and spatial drought evolution characteristics of Poyang Lake, and proposed that Poyang Lake has obvious aridity trend in spring and autumn. Chen et al. [8] analyzed the frequency and change of hydrological drought in Ganjiang and Fuhe sub-basins of Poyang Lake Basin on Copula. It can be seen that, the drought index calculated according to the precipitation series is an important index to judge the drought level. If there is inconsistency in precipitation series, the level and frequency of drought will be significantly impacted. However, in the current drought research of Poyang Lake Basin, few scholars have studied the inconsistency of precipitation series and the evolution characteristics of drought before and after the inconsistency in changing environment.

Aim to the problems above, considering the drought of Poyang Lake is mainly characterized by continuous drought in summer and autumn, the hydrological variation diagnosis system was used firstly to diagnose the variation of the precipitation series in summer and autumn at different stations at Poyang Lake basin, and then the generalized Pareto distribution (GP) was chosen to fit the series of the seasonal precipitation anomaly percentage (PA), the Copula finally used to analyze the probability of continuous drought events in summer and autumn, so as to study the characteristics of drought evolution at Poyang Lake. The results could provide some basis for the development of drought resistance and disaster reduction at Poyang Lake.

2. Overview of Poyang Lake Basin and precipitation data

2.1. Overview of Poyang Lake Basin
Poyang Lake is located in the South of the middle of the Yangtze River and in the East Asian monsoon region, the basin area is 162200 km², accounting for 8.97% of the total area of the Yangtze River Basin, and about 96.7% basin area is located in Jiangxi Province. The mean annual average precipitation of Poyang Lake is 1574.6mm, and the mean annual average temperature is 18℃, the annual average evaporation is 800-1200mm, and the annual average wind speed is 3m/s. Poyang Lake is the largest fresh water lake in China, it is a natural huff and puff seasonal lake, which receives the water of Ganjiang River, Fuhe River, Xinjiang River, Rao River and Xiushui river.

2.2. Overview of precipitation
Considering the length of precipitation series and the meteorological stations location, 9 meteorological stations such as Yichun, Nanchang etc. are selected for analysis. The basic information of each station is shown in Table 1, and the location of each station is shown in Figure 1.

| NO. | Station   | ID   | Beginning and ending years | Series length |
|-----|-----------|------|----------------------------|---------------|
| 1   | Yichun    | 57793| 1959-2016                  | 58            |
| 2   | Ji’an     | 57799| 1959-2016                  | 58            |
| 3   | Jinggangshan | 57894| 1959-2016                  | 58            |
| 4   | Suichuan  | 57896| 1959-2016                  | 58            |
| 5   | Jingdezhen| 58527| 1959-2016                  | 58            |
| 6   | Nanchang  | 58606| 1959-2016                  | 58            |
| 7   | Guixi     | 58626| 1959-2016                  | 58            |
| 8   | Nancheng  | 58715| 1959-2016                  | 58            |
| 9   | Guangchang| 58813| 1959-2016                  | 58            |
3. Analysis method

3.1. Hydrological variation diagnosis system

In 2010, Xie Ping put forward the hydrological variation diagnosis system for the variation diagnosis of hydrological and water resources series [9], which mainly considers two variation forms: trend and jump, and consists of three parts: preliminary diagnosis, detailed diagnosis and comprehensive diagnosis. It can not only identify the variation of time series as a whole, but also can identify the form and degree of variation of inconsistent series, test indicators are comprehensive, weight assignment is objective and diagnosis results are credible. The system solves the problem of recognize and test the variation and variation degree of time series as a whole, and the identify problem of different test results from many test methods.

In the preliminary diagnosis part, process line method, moving average method and Hurst coefficient method are used to test the series variation to determine whether there is variation in the series. If the result is no variation, it will be transferred to cause investigation and analysis to confirm the result; if there is variation, it will be transferred to the detailed diagnosis part.

In the detailed diagnosis part, a variety of mutation test methods are used to judge the variation of series, the trend variation and jump variation of series are analyzed respectively. For the trend variation, the trend variation classification and test method based on linear trend correlation coefficient, Spearman rank correlation test method and Kendall rank correlation test method are used to judge it; for the jump variation, the ordered clustering method, Lee heghinan method, rank sum test method, sliding F test
method, sliding t test method, run test method, optimal information bisection model, R/s test Methods, brown Forsythe, man Kendall and Bayesian methods are used to make judgment, and then the comprehensive diagnosis was carried out.

In the comprehensive diagnosis part, according to the detailed diagnosis results, the trend diagnosis conclusions are synthesized, and the jump diagnosis conclusions are synthesized. According to the efficiency coefficient, the fitting degree between hydrological series and trend component or jump component is evaluated, and the larger efficiency coefficient is taken as the result of variation form judgment. Finally, combining with the actual hydrological investigation and analysis, the form and conclusion of variation are confirmed, so as to get the most possible diagnosis result of variation. Therefore, this paper uses the hydrological variation diagnosis system to diagnose the variation of hydrological series.

3.2. Edge distribution function of continuous drought events in summer and autumn

The percentage of precipitation anomaly (Pa) was selected to evaluate the drought events in Poyang Lake Basin, and the statistical distribution model was used to fit the precipitation anomaly percentage series of each station. At present, the widely used probability distribution functions including: Generalized Extreme Value distribution (GEV), Generalized Pareto distribution [10] (GP), PIII distribution, gamma distribution, etc. GP distribution is selected in this study, and its cumulative distribution function is calculated as follows:

\[ F(x) = 1 - e^y \]

\[ y = \begin{cases} \frac{-\ln[1 - k(x - \xi)/\alpha]}{k}, & k \neq 0 \\ \frac{(x - \xi)/\alpha}{k}, & k = 0 \end{cases} \]

where: \( \alpha \) is the scale parameter, \( \xi \) is the position parameter and \( k \) is the shape parameter.

The parameters in GP distribution are estimated by L-moment method, which is developed from "probability weight moment" (PWM) and is a linear combination of probability weight moments. In this paper, Kolmogorov Smirnov (K-S) is used to test the fitting degree between sample distribution and known distribution, and the empirical frequency calculation formula adopts the following formula:

\[ H(x_m) = P(X \leq x_m) = (m - 0.44)/(n + 0.12) \]

where: \( P \) is the empirical probability of \( X \leq X_m \); \( m \) is the serial number of \( X_m \); \( n \) is the sample capacity.

3.3. Two-dimension copula joint distribution function

Copula functions are constructed by different edge distributions and their related structures [11]. There are three common types of Copula joint functions: elliptic, quadratic and Archimedean. In hydrological calculation, the two-dimensional Archimedean copula function is widely used. Different copula functions have different application area. In this paper, Clayton function is selected to construct the joint distribution function of drought events in summer and autumn, so as to analyze the characteristics of the occurrence probability of drought events in summer and autumn. The calculation formula is as follows.

\[ C(u, v) = (u^{-\theta} + v^{-\theta} - 1)^{-1/\theta} \]

\[ \tau = \theta/(1 + \theta) \]

The \( \theta \) is the value of the relationship between the two variables. In this study, the nonparametric [12] estimation method of Copula function proposed by Genest and Rivest was used to calculate the value of \( \theta \). Where, \( u \) and \( V \) are marginal distribution, the seasonal precipitation anomaly percentage series fitted by GP distribution, \( \tau \) Kendall coefficient of random samples, and the calculation formula is as follows:

\[ \tau = (C_n^2)^{-1} \sum_{i<j} sgn(x_i - x_j)(y_i - y_j) \]

where: SGN (·) is a sign function, \( Xi (i= 1, 2, ..., n) \), \( Xj (j= 1, 2, ..., n) \) and \( Yi (i = 1, 2, n) \), \( Yj (j = 1, 2, n) \) is a random sample, \( n \) is the number of random samples.
4. Analysis of the characteristics of drought evolution

4.1. Precipitation series variation diagnosis

Under the condition of the first reliability level $\alpha = 0.05$ and the second reliability level $\beta = 0.01$, the hydrological variation diagnosis system is used to diagnose the precipitation series of 9 meteorological stations, such as Yichun station and Nanchang Station in summer (June to August) and autumn (September to November). The diagnosis results of summer precipitation series are shown in Table 2 and autumn precipitation series is shown in Table 3.

| Summer (June to August) | Yichun | Jinxian | Jianggangshan | Shunchun | Jingdezhen | Nanchang | Gouxu | Nancheng | Guangchang |
|------------------------|--------|---------|--------------|----------|------------|---------|-------|---------|-------------|
| Hurst coefficient       | 0.718  | 0.696   | 0.713        | 0.7      | 0.737      | 0.693   | 0.733 | 0.748   | 0.668       |
| Total alteration degree | middle | weak    | weak         | weak     | middle     | weak    | middle| weak    | weak        |
| Shuang Feng Test        | 2007(-) | 2005(-) | 2010(-)      | 1906(-)  | 1958(-)    | 2009(-) | 1956(-)| 1976(-) | 1994(+)     |
| Shuang T Test           | 1992(-) | 1991(+)| 1992(+)| 1991(+) | 1992(+)    | 1991(+) | 1991(-)| 1991(+) | 1993(+)     |
| Lee-Rayleigh            | 1992(0) | 1991(0)| 1993(0)| 1991(0) | 1955(0)    | 1992(0) | 1991(0)| 1991(0) | 2012(0)     |
| Sequential Crystal      | 1992(0) | 1991(0)| 1992(0)| 1991(0) | 1992(0)    | 1992(0) | 1991(0)| 1991(0) | 1993(0)     |
| ES analysis             | 1990(0) | 1990(0)| 1998(0)| 1985(0) | 1998(0)    | 1990(0) | 1990(0)| 1991(0) | 1981(0)     |
| Seven-Phase             | 1991(-) | 1991(-)| 1995(-)| 1991(-) | 1992(-)    | 1992(-) | 1991(-)| 1991(-) | 1991(+)     |
| Shuang Run Test         | 1954(-) | 1984(+)| 1967(+) | 1994(+) | 2005(+)    | 2004(-) | 2000(-)| 2011(+) | 2012(+)     |
| Shuang Run-Sun Test     | 1991(-) | 1991(+)| 1992(+)| 1991(+)| 1991(+)    | 1991(+)| 1991(-)| 1991(+) | 1991(+)     |
| Optimal information two | 1973(0) | 1991(0)| 1994(0) | 2009(0)  | 2007(0)    | 1970(0) | 1979(0)| 1980(0) | 2005(0)     |
| organization            |        |        |        |        |           |        |        |        |             |
| Mann-Kendall            | 1976(+) | 1991(+) | 2005(+) | 2000(+)  | 1992(+)    | 1992(+) | 1991(+)| 1991(+) | 1993(+)     |
| Bayesian analysis       | 1992(+) | 1991(+) | 1992(+) | 1991(+)  | 1992(+)    | 1992(+) | 1991(+)| 1991(+) | 1993(+)     |
| Trendy alteration degree| none    | none    | none    | none     | none       | none    | none  | none    | none        |
| Relevant coefficient    | none    | none    | none    | none     | none       | none    | none  | none    | none        |
| Kendall                | -       | -       | -       | -        | -          | -       | -     | -       | -           |
| Spearman               | -       | -       | -       | -        | -          | -       | -     | -       | -           |
| Komposite             | 0.43    | 0.74    | 0.69    | 0.69     | 0.54       | 0.58    | 0.73  | 0.7     | 0.5         |
| Comprehensive significant | 3(-)   | 3(+)    | 2(-)    | 2(+)     | 2(+)       | 2(+)    | 3(+)  | 4(+)    | 3(+)        |
| Comprehensive significant | 3(-)   | 3(+)    | 2(-)    | 2(+)     | 2(+)       | 2(+)    | 3(+)  | 4(+)    | 3(+)        |
| Efficiency coefficient of jump alteration (%) | 10.74 | 7.09 | 8.94 | 11.64 | 9.15 | 7.62 | 9.56 | 16.38 | 7.03 |
| Efficiency coefficient of jump alteration (%) | 4.63 | 3.13 | 2.29 | 2.69 | 2.24 | 2.06 | 3.17 | 9.38 | 0.79 |
| FINAL result            | 1992(+) | 1991(+) | 1993(+) | 1991(+) | 1992(+)    | 1992(+) | 1991(+)| 1991(+) | 1993(+)     |

Where the "\(^{+}\)" means significant, not significant, could not be tested, decrease and increase.

| Autumn (Sept. to Nov.) | Yichun | Jinxian | Jianggangshan | Shunchun | Jingdezhen | Nanchang | Gouxu | Nancheng | Guangchang |
|------------------------|--------|---------|--------------|----------|------------|---------|-------|---------|-------------|
| Hurst coefficient       | 0.59   | 0.546   | 0.573        | 0.54     | 0.565      | 0.61    | 0.558 | 0.751   | 0.54        |
| Total alteration degree | none   | none    | none         | none     | none       | none    | none  | none    | none        |
| FINAL result            | none   | none    | none         | none     | none       | none    | none  | none    | none        |

It can be seen from table 2 that in the summer precipitation series of meteorological stations in Poyang Lake Basin, the precipitation series had a hydrological variation of jumping upward. The jumping points were all distributed in 1991-1993. The jumping points are concentrated, and the degree of variation is between weak variation and medium variation.

It can be seen from table 3 that there is no variation in autumn precipitation series of meteorological stations in Poyang Lake Basin, indicating that they all meet the requirements of consistency.
4.2. Precipitation series fitting of summer and autumn before and after variation

Based on the jump variation point in summer precipitation series, the summer and autumn precipitation series of the 9 stations could be divided into pre-variation and post-variation series. The GP distribution was used to fit the precipitation anomaly percentage of the selected stations in summer and autumn before and after variation, and the K-S test was used to calculate the K-S statistical value of the fitted GP distribution, the results shown in Table 4. The results show that, the seasonal precipitation anomaly percentage series before and after the variation of 9 stations accord with the GP distribution, and all passed the significance test of $\alpha=0.05$ (H=0 means to obey the GP distribution). Therefore, the GP distribution could be used to simulate precipitation anomaly series.

Table 4. GP distribution fitting and K-S testing results of summer and fall Pa series with the alteration.

| Station   | Time series period | k      | a      | h      | $p$  |
|-----------|--------------------|--------|--------|--------|------|
| Yichun    | summer pre-variation | 105.39 | 185.20 | 0      | 0.66 |
|           | summer post-variation | 223.30 | 303.11 | 0      | 0.83 |
|           | autumn             | 76.50  | 86.10  | 0      | 0.79 |
| J’nan     | summer pre-variation | 98.46  | 229.40 | 0      | 0.90 |
|           | summer post-variation | 164.40 | 295.34 | 0      | 0.96 |
|           | autumn             | 15.89  | 25.80  | 0      | 0.79 |
| Jinggangshan | summer pre-variation | 209.67 | 397.20 | 0      | 0.91 |
|           | autumn             | 338.60 | 526.13 | 0      | 0.89 |
|           | summer pre-variation | 86.40  | 132.40 | 0      | 0.45 |
| Suichuan  | summer pre-variation | 143.78 | 159.08 | 0      | 0.71 |
|           | summer post-variation | 250.30 | 265.90 | 0      | 0.59 |
|           | autumn             | 54.00  | 67.90  | 0      | 0.97 |
| Jingdezhen| summer pre-variation | 33.92  | 276.70 | 0      | 0.58 |
|           | summer post-variation | 224.50 | 467.28 | 0      | 0.49 |
|           | autumn             | 55.10  | 66.20  | 0      | 0.61 |
| Nanchang  | summer pre-variation | 183.50 | 352.30 | 0      | 0.56 |
|           | summer post-variation | 300.40 | 349.30 | 0      | 0.47 |
|           | autumn             | 48.00  | 49.50  | 0      | 0.92 |
| Guixi     | summer pre-variation | 206.10 | 309.60 | 0      | 0.90 |
|           | summer post-variation | 49.80  | 69.30  | 0      | 0.88 |
|           | autumn             | 94.80  | 174.30 | 0      | 0.67 |
| Nancheng  | summer pre-variation | 219.10 | 298.30 | 0      | 0.75 |
|           | summer post-variation | 45.40  | 51.70  | 0      | 0.97 |
|           | autumn             | 144.10 | 191.59 | 0      | 0.97 |
| Guangchang| summer pre-variation | 252.10 | 299.50 | 0      | 0.92 |
|           | autumn             | 20.10  | 22.00  | 0      | 0.93 |

4.3. Parameter calculation of two-dimension copula distribution function

Based on the relationship between Kendall rank correlation coefficient $\tau$ and copula function parameter $\theta$, the Clayton distribution function parameters of 9 stations in Poyang Lake Basin are calculated. The results are shown in Table 5.

Table 5. The parameter results of Copula.

| Station   | pre-variation $\theta$ | post-variation $\theta$ |
|-----------|------------------------|-------------------------|
| Yichun    | 0.014503               | 0.036744                |
| Ji’an     | 0.023610               | 0.016218                |
| Jinggangshan | 0.185467       | 0.212375                |
| Suichuan  | 0.000001               | 0.000001                |
| Jingdezhen| 0.000001               | 0.049524                |
| Nanchang  | 0.000001               | 0.000001                |
| Guixi     | 0.057987               | 0.070121                |
| Nancheng  | 0.038710               | 0.053221                |
| Guangchang| 0.129439               | 0.131106                |
4.4. Frequency analysis of continuous drought events in summer and autumn

Take Pa<25% as the standard to judge the occurrence of drought [13], and the continuous drought events in summer and autumn defined as continuous drought if Pa is less than -25% both in summer and autumn. Based on the edge distribution of seasonal precipitation anomaly percentage before and after each variation, and the joint distribution of Clayton between summer and autumn, the frequency of summer and autumn continuous drought events in Poyang Lake basin could be calculated, the results shown in Table 6 and Figure 2.

**Table 6.** The frequency results of continuous drought in summer and fall.

| Station   | pre-variation | post-variation | difference value |
|-----------|---------------|----------------|------------------|
| Yichun    | 0.1488        | 0.0580         | 0.0907           |
| Ji’an     | 0.2243        | 0.1428         | 0.0815           |
| Jinggangshan | 0.0212      | 0.0048         | 0.0164           |
| Suichuan  | 0.1026        | 0.0451         | 0.0575           |
| Jingdezhen | 0.1145       | 0.0209         | 0.0936           |
| Nanchang  | 0.1653        | 0.0554         | 0.1100           |
| Guixi     | 0.0756        | 0.0200         | 0.0556           |
| Nancheng  | 0.1255        | 0.0388         | 0.0867           |
| Guangchang | 0.1397       | 0.0581         | 0.0816           |

**Figure 2.** Evolution characteristics plot of summer-autumn consistent drought frequency.
It can be seen from table 6 that the occurrence probability of summer and autumn continuous drought events in Poyang Lake Basin is generally as downward trend, and the frequency of each meteorological station after variation is lower than that before variation, indicating that the recurrence period of summer and autumn continuous drought has increased, among which Nanchang meteorological station is the most obvious one, Yichun and Jingdezhen meteorological stations are the second, while Jinggangshan meteorological station is not obvious.

5. Conclusion
Precipitation series is always used to calculate the drought parameters and judge the drought frequency. At present, not too much scholars to research drought of Poyang Lake under inconsistency of precipitation series in the changing environment, and the evolution characteristics of drought in the basin before and after the inconsistency. In this paper, the hydrological variation diagnosis system was used to study the nine meteorological stations in summer and autumn. Based on the results of variation diagnosis, the probability of continuous drought in summer and autumn at each meteorological station is calculated by taking the percentage of precipitation anomaly as drought index and copula function, so as to analyze the characteristics of drought evolution at Poyang Lake. The main conclusions are as follows:

(1) To the precipitation series of summer and autumn, the precipitation variation in Poyang Lake Basin occurs in summer, and there is no variation in autumn precipitation series, the autumn precipitation series meets the requirements of consistency.

(2) The time period of variation of summer precipitation series is mainly concentrated in the early 1990s. In terms of variation form, the summer precipitation series has a jump up variation, which means, the annual average precipitation has increased after variation compared with that before variation.

(3) After variation, the occurrence probability of summer and autumn continuous drought events in Poyang Lake Basin decreased compared with that before variation, and the frequency of each meteorological station after variation decreased compared with that before variation, indicating that the recurrence period of summer and autumn continuous drought events increased.

(4) In the case of increasing return period of summer and autumn continuous drought, the main factor leading to the increasingly serious drought in Poyang Lake Basin is not the impact of water input, that is, precipitation, but the impact of water expenditure. For Poyang Lake, the ways of water expenditure include evaporation, human production and living water, lake outflow and other factors. The contribution of these factors to the formation of drought is different. We should further strengthen the attribution analysis and Research on the inconsistency of drought in Poyang Lake Basin.

In the future research, more relevant data should be collected, encrypt research sites, and analyze the evolution characteristics of summer and autumn continuous drought in Poyang Lake Basin under the changing environment in more detail.

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