

Study on the Stage of Flood Season in Typhoon Affected Area --A case study in Tingxia

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Abstract. Based on the climatic conditions and weather system in the Zhejiang Province, the Tingxia Reservoir in the typhoon affected area was selected as the research object. The fractal theory and the Fisher optimal method were used to quantitatively analyse the stages. Based on the analysis of the background of weather conditions, a combination of qualitative and quantitative methods is used to reasonably determine the flood season staging scheme for reservoirs, in order to solve the problem of the operability of the reservoir caused by the sudden change of water level during the flood season, which is based on comprehensive analysis. By the staging of the flood season to achieved the reasonable transition between the controlled water level in each stage and the controlled water level in the flood season and non-flood season.

1. Introduction

To study the seasonal variation characteristics of weather system, rainstorm and flood, the partition Of flood season are usually used as the main research method. As reported by the meteorological department of China, the average annual rainfall per ten-day is greater than or equal to 1.5 times the average precipitation per ten days, which is called flood season^[1]. The above-mentioned ideas for the phase of the flood season have been continuously summarized and improved, and two types of analysis methods have been gradually formed: genetic analysis method and mathematical statistics method. The causal analysis method^[2-3] uses the seasonal motion laws such as the weather system and the atmospheric circulation system that cause storm floods in the basin to analyze the exact meaning of the “flood season” or “main flood season” of the river basin. The physical concept of the method is clear and the result is reasonable. It has been widely adopted because of its high reliability. However, for the reservoir basin, especially for large watersheds, the cause of the formation of heavy rains is complicated. There are many combinations of different causes, and thus the workload is large. At the same time, the staging is subjective and difficult. Different from the genetic analysis method, the mathematical statistics method^[4-6] is the use of measured historical flow (rainfall) data, select statistical indicators, analysis of changes in the index within the year (or flood season), and finally through mathematical statistics theory to obtain changes in the flood season rate.

Compared with the genesis analysis method, the mathematical statistics method is simple and clear, but the selection of the characteristic index and frequency standard is obviously subjective, which affects the objectivity of the staging result. Genesis analysis method and mathematical statistics method are qualitative analysis methods, and have common defects. That is, there is a lack of scientific mathematical calculation basis for how to stage, and the stage is uncertain. Therefore, it is



necessary to use scientific quantitative analysis methods to make up for the deficiencies of qualitative methods and provide scientific basis for the reasonable stage of the flood season.

In recent years, with the development of the understanding of hydrological phenomena and the nature of mathematics, scholars have proposed some new methods of quantitative staging based on relevant research methods and achievements in mathematical statistics, geometry and other fields. Such as the fractal method, change point analysis method, fuzzy system clustering method, vector statistics method and relative frequency method.

From the perspective of the entire development process, the research on the stage of flood season is a transition process from the qualitative analysis to the application of quantitative methods. It is also a process of transition from subjective perception to objectivity analysis^[7-8]. Due to the deterministic, random, and transitional characteristics of the “flood season” change rule, in the next phase of the flood season, we should start from the seasonal changes in the circulation weather system, and combine the qualitative and quantitative methods according to the characteristics of the monsoon climate in China. Analysis, in order to establish a set of perfect theories and methods of the stages of the flood season.

2. Methodology

2.1. Quantitative description of staging

From the perspective of mathematics, the study of the time history distribution of flood can be considered as a cluster analysis of time series. Usually, the staging of flood seasons is used as the main analysis method. The quantitative description of flood seasons is as follows:

Taking the flood seasons as the universe X and the period t within the flood season be d =considered as the research object, which denoting as $X_t = X_1, X_2 \dots X_n$, and extract the m indices describing the characteristics of the object (rainfall, runoff, etc.), assuming the k ($k=1, 2, \dots, m$) of the object X_i as x_{ik} , then X_i can be expressed by the m index eigenvalues, denoted by $X_i = (x_{i1}, x_{i2}, \dots, x_{im})$ ($i = 1, 2, \dots, n$). According to the principle of clustering, all the objects X_t are divided into k classes, and the corresponding time period subsets are the various stages of the flood season.

As a cluster analysis, the stage of flood season also has some inherent characteristics:

(1) There are many impact factors, and the flood season is influenced by comprehensive factors such as the weather system and the land surface. It is reflected in the basin surface that not only rainfall, but also surface runoff, etc., the staging of the flood season should be analysed by combining multiple indicators.

(2) The sequentially of hydrological series is heavy strongly, and the flood season series cannot destroy the time continuity of the hydrological series samples.

(3) In addition to show how to divide the period of the flood season, the criteria for the optimal number of stages to solve the optimal problem in several phases also should be given.

2.2 Methods of staging

2.2.1. Fractal method. In 1973, Professor B.B. Mandelbrot of the IBM Research Centre of the United States proposed the concept of fractal dimension and fractal geometry during his first lecture at the College of France. In 1977, he established the fractal theory formally. The basic idea of fractal geometry is that objective things have a self-similar hierarchical structure, and the locality and the whole have statistical similarities in form, function, information, time and space, and are called self-similarity. Mandelbrot proposes that the part is similar to the whole within some form, which is called fractal.

Analysing hydrological processes, no matter how complex their influence factors are, just like other natural phenomena, they all have fractal characteristics such as nonlinearity and similarity. Therefore, we can use fractal theory to study flood season. The fractal quantification method is fractal dimension, and the capacity dimension is the most commonly used fractal dimension.

Assuming that the graph to be considered is a bounded set in the n-dimensional Euclidean space R^n , when the set is covered with a sphere with a radius of ε , the minimum number of balls $N(\varepsilon)$ is obtained. The capacity dimension D_c can be defined as:

$$D_c = \lim_{\varepsilon \rightarrow 0} \frac{\ln N(\varepsilon)}{\ln 1/\varepsilon}$$

According to the definition of the capacity dimension, it is possible to infer the capacity dimension of the hydrological series according to the time series. The specific process is as follows: Take the hydrological process point data series X_1, X_2, \dots, X_n , according to its time span, determine the total time period T. To determine the sample fixed value Y_T that can reflect a flood period, use a certain time period ε as the time scale, measure the number of the time period exceeding Y_T , and calculate the relative measure $NN(\varepsilon) = N(\varepsilon)/NT$, where $NT = N/\varepsilon$. Draw the relevant line $\ln NN(\varepsilon) \sim \ln \varepsilon$, determine the line segment that exists, find the slope b of the line, and calculate the volume dimension of the sample fractal $D_c = 2 - b$ with a period T. Repeat the above steps to find the capacity dimension of T D_c in different time periods. If D_c is approximately equal at a certain time period, this T period is a stage determined by the fractal method.

2.2.2. Fisher optimal method. This method is a statistical method for classifying ordered samples. As a traditional linear classification method, this method has been successfully applied in many areas such as agricultural divisions, weather forecasting, earthquake cycle forecasting, industrial product detection, and medical analysis. The theory used to classify is based on the smallest sum of squared deviations of the sample, and the principle of segmentation is to make the difference between the samples within each segment (class) the smallest, and the difference between the segments (classes) is the largest. The specific process is as follows:

For the ordered sample n, m indices the sample characteristics, and the eigenvalues are x_1, x_2, \dots, x_n (each has m-dimensional vector). The mean vector and diameter of a category x_i, x_{i+1}, \dots, x_j ($j > i$) is assumed as:

$$\bar{x}_{ij} = \frac{1}{j-i+1} \sum_{l=i}^j x_l$$

$$D(i, j) = \sum_{l=i}^j \left(x_l - \bar{x}_{ij} \right) \left(x_l - \bar{x}_{ij} \right)$$

If ordered samples n is divided into k classes, one of the following points is:

$$P(n, k) : [i_1, i_1 + 1, \dots, i_2 - 1], [i_2, i_2 + 1, \dots, i_3 - 1], \dots, [i_k, i_k + 1, \dots, n]$$

Where: $1 = i_1 < i_2 < \dots < i_k \leq n$.

The error function of this division method is defined:

$$e[P(n, k)] = \sum_{j=1}^k D(i_j, i_{j+1} - 1)$$

When the n and k are fixed, the smaller $e[P(n, k)]$, the smaller the diameter of each type, the more reasonable the classification. Find the $e[P^*(n, k)]$ minimum value of $e[P(n, k)]$, then determine

the optimal classification number drawing the correlation curve $e[P^*(n, k)] \sim k$ from the k value at the inflection point of the curve.

3. Study case

The basin considered in the following example is Tingxia, located in the southeast of China, with a drainage area of 176 km². The climate is relatively humid and belongs to the semi-humid region. From the analysis of observed data, 68.9% of the mean annual rainfall falls between March and June, while evaporation is greatest between May and September. In this study, 47 years of historical 1961-2007, including hourly precipitation, pan evaporation and discharge, were used for analysis. The runoff data are calculated based on the change in the water level of the reservoirs. The rainfall data are obtained from rain gauges near the dams. The daily evaporation data are obtained by using daily evaporation pan data from evaporation station near the dams.

4. Application results

4.1. Fractal method

Tingxia Reservoir's daily maximum precipitation is the sample, each half-month is the calculation interval, taking the difference in fractal dimension (generally 5%) as a category, and calculate the next category at the starting point when the difference is larger. Then get the fractal dimension of the maximum precipitation of the Tingxia Reservoir showed in Table 1 to Table 4.

Table 1 The fractal dimension of the maximum precipitation of the Tingxia Reservoir (a)

Start time	End time	Fractal dimension	Relative error (%)
April 15	April 30	1.3970	
April 15	May 15	1.4302	2.32
April 15	May 31	1.4177	0.88
April 15	June 15	1.4712	3.64
April 15	June 30	1.4955	1.62
April 15	July 15	1.5636	4.36
April 15	July 31	1.4513	7.74

Table 2 The fractal dimension of the maximum precipitation of the Tingxia Reservoir (b)

Start time	End time	Fractal dimension	Relative error (%)
July 16	July 31	1.2455	
July 16	August 15	1.4509	14.16
July 16	August 31	1.3830	4.91

Table 3 The fractal dimension of the maximum precipitation of the Tingxia Reservoir (c)

Start time	End time	Fractal dimension	Relative error (%)
August 1	August 15	1.4213	
August 1	August 31	1.3704	3.71
August 1	September 15	1.4166	3.26
August 1	September 30	1.2909	9.74
August 1	October 15	1.4652	11.90

Table 4 The fractal dimension of the maximum precipitation of the Tingxia Reservoir (d)

Start time	End time	Fractal dimension	Relative error (%)
September 16	September 30	1.4066	
September 16	October 15	1.4328	1.9

According to the calculated fractal dimension, 5% is the control margin of the fractal dimension of the adjacent two phases. Based on the calculation results in Tables 1 to 4, the flood season can be roughly divided into the following stages:

Stage1: April 15~July 15;

Stage2: July 16~July 31;

Stage3: August 1~September 15;

Stage4: September 16~October 15.

4.2. Fisher optimal method

The Fisher optimal method is used to calculate the stage, the relativity between $e[P^*(n, k)]$ and k is revealed in Table 5 and Figure 1. As can be seen from Table 5 and Figure 1, the minimum objective function is monotonically decreasing with the k value. From Fig. 1, it can be seen that there is a significant inflection point at 5, and then the value of the objective function tends to be flat, that is, the significance of increasing the value of k is not obvious.

Table 5 The relativity between $e[P^*(n, k)]$ and k

k	$e[P^*(n, k)]$	Stage results
2	31.42	(1 2 3 4)(5 6 7 8 9 10 11 12 13)
3	24.18	(1 2 3 4)(5 6 7 8 9 10 11)(12 13)
4	15.18	(1 2 3 4)(5 6 7 8)(9 10 11)(12 13)
5	7.29	(1 2 3 4)(5 6 7)(8)(9 10 11)(12 13)
6	3.88	(1 2 3 4)(5 6 7)(8)(9 10 11)(12)(13)
7	1.76	(1 2 3 4)(5)(6 7)(8)(9 10 11)(12)(13)
8	0.98	(1 2 3 4)(5)(6 7)(8)(9)(10 11)(12)(13)
9	0.51	(1 2)(3 4)(5)(6 7)(8)(9)(10 11)(12)(13)
10	0.3	(1 2)(3 4)(5)(6 7)(8)(9)(10)(11)(12)(13)
11	0.15	(1 2)(3 4)(5)(6)(7)(8)(9)(10)(11)(12)(13)
12	0.01	(1 2)(3)(4)(5)(6)(7)(8)(9)(10)(11)(12)(13)

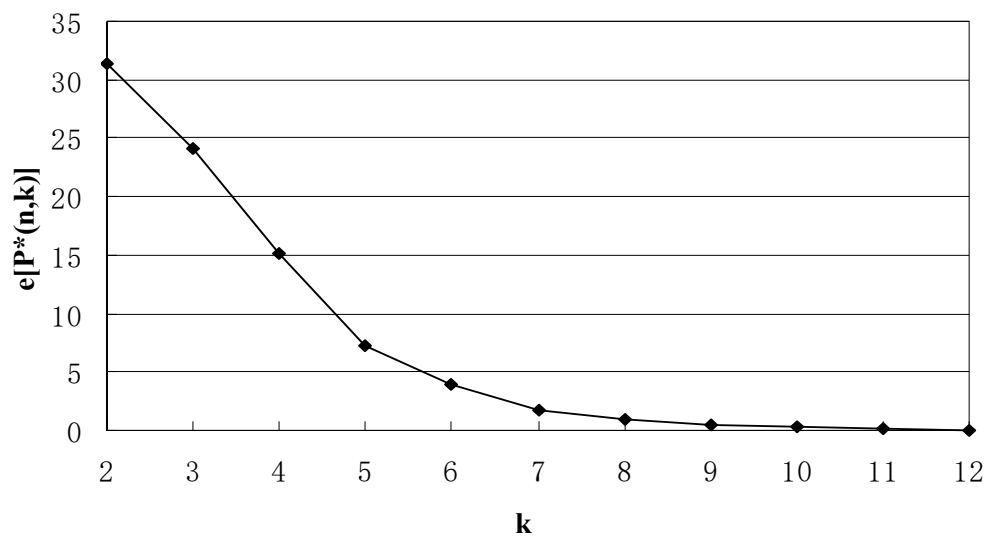


Figure 1 The correlation curve between $e[P^*(n,k)]$ and k

The k -optimal value is 5, dividing the flood season into:

Stage1: April 15~May 31;

Stage2: June 1~July 15;

Stage3: July 16~ July 31;

Stage4: August 1~ September 15;

Stage5: September 16~October 15.

5. Summary and Conclusion

Traditionally, setting only one limit water lever during the whole flood season is not consistent with the regularity of storm floods in the flood season. This rule can be fully utilized by the staging of the flood season, and it can be used through staged dispatching and dynamic control of the limited water level to bring into play the reservoir's comprehensive utilize potential to achieve to use of floodwater resources safety. This paper used fractal method and fisher optimal method to stage the flood season in Tingxia reservoir. The fractal method divides the flood season into four stages by fractal dimension calculation, 4.15 to 7.15, 7.16 to 7.31, 8.1 to 9.15, and 9.16 to 10.15. The fisher optimal suggests that the reservoir flood season is divided into 5 categories. The difference is the first stage, and the rest of the session is the same. Considering the rainstorm frequency and rainfall characteristics during the Typhoon period of the Tingxia Reservoir, it is recommended that the results be calculated using the fractal method.

It should be pointed out that global warming is increasingly intensifying and extreme weather occurs frequently. For reservoirs located in the typhoon area, attention is paid to the traditional main flood season from July to September, and from the end of September to October. On the 15th, this traditional sense is not likely to occur during the time period of the heavy rain process. Close attention should be paid to monitoring the changes in the weather system. Once the superposition of multiple weather systems or the abnormal tropical cyclone activity path may affect eastern of Zhejiang, Immediate pre-discharge measures shall be adopted to timely pre-discharge the reservoir water volume, so as to ensure safety for the excessive flow process that may occur in the later period.

Acknowledgments

This study is supported by the Zhejiang Provincial Research Institute Support Fund (2018F10027).

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