Reasonable determination of the utilizable capacity of water conservancy project based on prediction

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Abstract. With the rapid development of society and economy in Danfeng county, the contradiction between supply and demand of water resources has become increasingly prominent. In order to meet its growing water demand, it is proposed to build the Qingfeng Reservoir and realize joint water supply with the original Longtan Reservoir. Establishing a combined model of wavelet artificial neural network to predict runoff can increase the sequence length, which aims to construct a longer inflow sequence. Draw up different scales of utilizable capacity to carry out the joint water supply adjustment calculation of the two reservoirs. It is finally determined that the optimal utilizable capacity of Qingfeng Reservoir is 2 million m³, which meets the design assurance rate requirements of urban life and industry production. This method improves the reliability and rationality of the calculation result, and can provide some reference for the determination of the utilizable capacity of other water conservancy projects.

1. Introduction

As Danfeng county is integrated into the Guanzhong-Tianshui National Economic Zone, the economic transformation is gradually realized, the scale of the city is expanding, and the demand for water is growing. The current water supply sources of the county mainly include the water plant in the east of Danfeng county built in 2004, the emergency water source wells along the Danjiang River, and other self-contained water source wells. The water source of water plant is Longtan Reservoir of Yongyu River. There is less water flowing into it, and with the increase of operation years, the effective storage capacity is reduced. The emergency water source wells have low water guarantee and high water cost, which is difficult to meet the requirements of population and industrial development in Danfeng county. In addition, there are still more than 30,000 residents around the county town who use their own water source wells as their living water source and do not use tap water. The serious shortage of water supply of the county and the continuous increase in urban water demand have sharply contradicted, seriously restricting economic and social development and the improvement of people's living standards. In order to alleviate this contradiction and achieve sustainable development of the regional society, environment and economy, it is proposed to open up a new water source to increase the water supply volume and ensure the safety of water supply.

The Ziyu River on the east of the Yongyu River has good water quality, no current water users, and has good condition for building reservoir. It is planned to build a new water source project in the lower reaches of the Ziyu River, Qingfeng Reservoir, and realize the joint water supply with the original Longtan Reservoir. The Ziyu River Basin is a non-data area. The average annual runoff at the...
The water supply capacity of Qingfeng Reservoir depends on the needs of users and the scale of the project determined by the runoff conditions at the dam site. Therefore, the scale of the project is an important part of the planning and design of the new water supply project. The characteristic parameters of water conservancy projects aiming at water supply are the key to engineering design, which directly affects the scale and economic indicators of the project, and has important research significance and practical value. Runoff regulation calculation is an important step to determine the design scale of the reservoir [1]. There is usually insufficient number of cycles because of the limited length of the runoff sample in the traditional long series calculation, especially when the water guarantee rate is high, in the face of rare runoff changes and combinations, the analysis results are contingent and not very reliable [2,3]. In order to solve this problem, this paper combines the neural network model based on wavelet analysis to predict the runoff, and introduces the predicted runoff sequence of the planned year into the long series runoff adjustment calculation, which extends the runoff sample length. An improved long series adjustment calculation method is proposed and applied to the solution of the Qingfeng Reservoir's utilisable capacity, which provides a certain reference for
other water conservancy projects under high water use guarantee rate.

2. Analysis of runoff evolution in Wuguan River Basin
The regulation of runoff variation is complex, with randomness and uncertainty. Therefore, it is necessary to study the variation characteristics of runoff series before prediction. At present, the main methods used in the analysis of hydrometeorological trend are: linear tendency estimation method, Mann-Kendall method, cumulative anomaly method, cubic spline function, and moving average method [4]. Considering the characteristics of Wuguan River runoff data, this paper uses cumulative anomaly method and MK trend test method to analyze the trend of runoff variation. However, this usually only analyzes the trend in the current time, and it is unknown whether the trend will continue this trend in the future. In order to study whether the current trend will change in the future, this paper calculates the Hurst index by R/S analysis and quantitatively analyzes the persistence of the trend of the runoff series [5].

- Cumulative anomaly method
  The cumulative anomaly method is a commonly used method for judging the change trend by curve, which can more clearly show or distinguish the stage of interannual variation of runoff [6]. The cumulative runoff anomaly curve of the Wuguan River from 1959 to 2014 is plotted, as shown in figure 2. It can be seen from figure 2 that the runoff of Wuguan River increased from 1959 to 1965, decreased from 1965 to 1979, and increased from 1979 to 1985. The runoff of Wuguan River from 1985 to 2014 is fluctuant obviously, but overall shows the downward trend.

- Mann-Kendall trend test
  The Mann-Kendall nonparametric statistical method recommended by the World Meteorological Organization is widely used. It can effectively distinguish whether a natural process is in natural fluctuation or there is a certain change trend [7]. Using this method to analyze the annual runoff trend of Wuguan station. According to the calculation, the Kendall rank correlation coefficient $U$ is -0.6244. It illustrates that the runoff shows a downward trend. However, it doesn’t pass the significant test by the significance level $\alpha = 0.05$, indicating that the reduction trend is not obvious.

- R/S analysis
  The R/S analysis method can be used to explore the long-term memory process of nonlinear systems. It is a nonparametric analysis method [8]. Perform R/S analysis on the annual runoff sequence of Wuguan station and draw the lg(R/S) fitting map, as shown in figure 3. It can be seen from the fitting formula in figure 3 that the Hurst index of the annual runoff of Wuguan station is 0.4813. This is slightly less than 0.5, indicating that the runoff series in each period has anti-
persistence, that is, the runoff will show a weak upward trend in the future.

3. Annual runoff forecast of Wuguan River based on wavelet neural network model

Wavelet analysis obtains the time information of the signal by translating the mother wavelet, and obtains the frequency characteristic of the signal by scaling the width of the wavelet. When the runoff sequence is decomposed by wavelet transform, the random components in the original sequence will be filtered out, and the trend components and periodic components will gradually appear [9]. Artificial neural network (ANN) is a complex network system formed by a large number of interconnected neurons. It mainly includes two algorithmic processes: firstly, the actual output value of each neuron node is calculated from the input layer through the hidden layer to the output layer one by one, which is called the forward transfer process of information flow; secondly, according to the error between the actual output and the expected output of the network, the connection weight of each neuron layer is modified step by step from the back to the front, which is called the reverse modification process of error [10]. The wavelet artificial neural network (WANN) is a hybrid model which mainly includes the wavelet decomposition of hydrological time series and the construction and weight learning of artificial neural network model. Firstly, the signal is preprocessed by wavelet analysis, and the good localization function of wavelet analysis in time domain and frequency domain is used to realize the feature extraction of the signal. Then the extracted feature vectors are sent to the neural network for processing, giving full play to the multi-resolution function of wavelet analysis and the non-linear approximation function of artificial neural network [11].

In this paper, the Mallat algorithm based on the single-layer one-dimensional discrete wavelet transform DWT [12] is used to decompose the original runoff sequence of the Wuguan River Basin from 1959 to 1999 into two sequences: the high frequency part and the low frequency part. The wavelet decomposition diagram is shown in figure 4. The input layer of WANN model are the scalar form of time, original sequence and decomposed sequences, and the output layer of the model is the runoff sequence from 1959 - 2014. Through the trial and error method, the number of hidden nodes of the neural network is determined to be 13. Thus the artificial neural network prediction model with the structure of 4-13-1 is constructed. The runoff data from 1959 to 1999 is used as the training sample, and the number of trainings is selected as 5000 times. In order to verify the accuracy of the model, the runoff data from 2000 to 2014 is used as the prediction sample.

![Wavelet decomposition of the annual runoff sequence in the Wuguan River.](image)

Prior to training, the sequence is normalized using equation (1).

\[
y = \left( y_{\text{max}} - y_{\text{min}} \right) \frac{x - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} + y_{\text{min}}
\]  

(1)
In the formula, \( x \) is the data before processing. After standardization, the data is within \([-1, 1]\), which is beneficial to network training.

Figure 5 plots the annual runoff predicted by the WANN model against the original sequence. According to the calculation, the relative error is basically within 10\%, and the model accuracy is good.

![Figure 5](image)

**Figure 5.** Comparison of the measured and the predicted values by the WANN model.

The WANN model is used to predict the runoff of the Wuguan River Basin in the next few years, and the results are shown in table 1.

**Table 1.** The predicted annual runoff of Wuguan River in the next year by the WANN.

| Year | Predicted Value/10^6 m³ |
|------|-------------------------|
| 2015 | 1.63                    |
| 2016 | 1.73                    |
| 2017 | 0.94                    |
| 2018 | 0.82                    |
| 2019 | 1.29                    |
| 2020 | 0.91                    |
| 2021 | 0.65                    |
| 2022 | 0.65                    |

4. **The joint water supply adjustment calculation based on the constructed water sequence**

![Flowchart](image)

**Figure 6.** Flow chart of adjustment calculation of Qingfeng Reservoir and Longtan Reservoir.

Longtan and Qingfeng reservoirs are jointly adjusted, and the main water planning and management of
water resources and water provision source is still Longtan Reservoir. When the water supply of the Longtan Reservoir is insufficient, the Qingfeng Reservoir will be replenished with water, and the excess water will be stored in the Qingfeng Reservoir. When the Qingfeng Reservoir is full, it will be filled into the Longtan Reservoir through the water supply tunnel. The joint adjustment process of the two reservoirs is shown in figure 6, in which S represents the water supply of Longtan Reservoir, D represents the water demand of users, and the green line is the main water supply line.

4.1 Water supply task and water supply guarantee rate
The water supply task of Qingfeng Reservoir is to guarantee certain water security for the residents' living and industrial production in Danfeng county. The comprehensive design level is 2030. The two reservoirs are jointly adjusted to ensure that the water supply guarantee rate of living and industrial parks is not less than 95%.

4.2 Runoff adjustment calculation data
- Water sequence
  There is no hydrological station in the Ziyu River Basin where the Qingfeng Reservoir is located and the Yongyu River Basin where the Longtan Reservoir is located. The long series of monthly runoff data required for water supply adjustment calculation can be calculated by the hydrological comparison method and corrected by the measured rainfall, which are based on the data of Wuguan station, including the measured data (from 1959 to 2014) and the forecast data (from 2015 to 2030).
- Water demand forecast
  One should refer to the “13th Five-Year Plan for National Economic Development of Danfeng County”, and use the quota method to predict the domestic water demand and industrial water demand within the planned annual of Danfeng county. The total water demand of residents and industry in Danfeng county in 2030 is 4.14 million m$^3$.
- Ecological flow
  The ecological base flow adopts the Tennant method [13], which is proposed by Tennant and other experts in 1976 to evaluate the health status of habitats. The core of this method is to find the annual or monthly average discharge of natural rivers, and to classify the ecological water demand of rivers by giving the percentage of stages [14]. In this paper, 10% of the annual average runoff is taken as the minimum ecological water demand of rivers. The calculation shows that the ecological base flow of the river below the Qingfeng Reservoir dam site is 0.021 m$^3$/s, and the ecological flow of the river below the dam site of Longtan Reservoir is 0.024 m$^3$/s.
- Evaporation and leakage
  The water surface evaporation of the reservoir is converted into the evaporation of large water surface by the evaporation measurement data of Hanjiang (Danfeng station). The land surface evaporation is calculated from the rainfall of Qingfeng Reservoir (Danfeng station) and runoff depth.
  The geological conditions in the two reservoir areas are good, so the leakage is estimated by 1% of the monthly water storage capacity of the reservoir.
- Silt capacity and the lowest pool level
  The siltation amount of Qingfeng Reservoir is calculated by referring to the actual siltation amount of Longtan Reservoir. According to the engineering design, the lowest draw-down level of Qingfeng Reservoir is 705.5 m.a.s.l., the dead storage capacity is 1.0554 million m$^3$, and the remaining dead storage capacity is 0.384 million m$^3$ after 30 years of siltation.

4.3 Two-reservoir joint water supply adjustment calculation
It is planned to carry out the runoff adjustment calculations of the utilizable capacity of 1.6 million m$^3$, 1.8 million m$^3$, 2 million m$^3$, and 2.2 million m$^3$. The comparison of the results of different water storage is shown in table 2.
Table 2. Results of the two reservoirs joint adjustment under different utilizable storage.

| utilizable storage /10^3 m³ | 160 | 180 | 200 | 220 |
|-----------------------------|-----|-----|-----|-----|
| average water supply of two reservoirs /10^3 m³ | 393.25 | 397.68 | 400.84 | 403.67 |
| average water supply of Qingfeng Reservoir /10^3 m³ | 120.71 | 125.14 | 128.30 | 131.13 |
| Water supply guarantee rate | 92.59 | 94.21 | 95.14 | 96.30 |

It can be seen from table 2 that when the utilizable storage is 2 million m³, the total water supply of the two reservoirs is 4.0084 million m³, in which the annual average annual water supply of the Qingfeng Reservoir is 1.283 million m³. The number of normal water supply periods for the two reservoirs is 822, the total number of damage periods is 42, and the water supply guarantee rate is 95.14%, meeting the design guarantee rate requirements for urban living and industrial water.

Therefore, it is finally determined that the Qingfeng Reservoir has an utilizable storage capacity of 2 million m³, and the normal storage capacity of the lower dam site is 2.384 million m³, and the corresponding normal water elevation is 721.08 m.

5. Conclusions

Through the above calculation and analysis, the following conclusions are drawn:

- According to the analysis of cumulative anomaly method and Mann-Kendall trend test method, the annual runoff of Wuguan River Basin has shown no significant downward trend since 1950s. According to the results of R/S analysis, the runoff of Wuguan River in each period has anti-sustainability, that is, the runoff will show a weak upward trend in the future.
- Introducing the wavelet analysis into the traditional neural network model, a combined forecasting model of wavelet neural network is established, which gives full play to the advantages of both. The annual runoff of Wuguan River are forecasted and tested, and the results show that the model has good accuracy.
- The sample length of runoff is extended by prediction, and a longer flow sequence is constructed by combining the measured runoff series with the predicted runoff series. The utilizable capacity of Qingfeng Reservoir is determined to be 2 million m³ through the joint water supply regulation calculation of the two reservoirs. This method makes the results more reliable and reasonable, and can provide some reference for the solution to the utilizable capacity of other reservoirs.

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