Analysis on the Variation Trend of Evaporation and Precipitation in Xiaolangdi Reservoir

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Abstract. Based on the monthly evaporation and precipitation data from 1982 to 2013 of 13 meteorological stations in and around the Xiaolangdi Reservoir, the linear tendency estimation method, cumulative anomaly, M-K mutation detection method and ARIMA model are used to study and predict the changing characteristics of evaporation and precipitation. The results show that the annual evaporation and precipitation in the reservoir area both show a downward trend. The evaporation has an abrupt decline in 2001, and the precipitation decreases suddenly in 2003 and 2011. After impoundment, the annual evaporation volume changed from the upward trend to a weak downward trend, and the downward trend of annual precipitation is weakened. The impact of impoundment on evaporation and precipitation is limited, and the impact intensity decreases with increasing distance from the reservoir. The reservoir area's evaporation and precipitation have significant seasonal variation characteristics, and the future evaporation will show a slight downward trend, while the precipitation will show a slight upward trend.

Keywords. Xiaolangdi Reservoir; evaporation; precipitation; trend analysis.

1. Research background
Meteorology and ecological environment are the key issues of today's society. Evaporation and precipitation can reflect climate change, and climate change will not only affect the surface hydrological cycle [1-3], but also affect the dynamic carrying capacity of water resources and the sustainable development of the economy and society [4]. Evaporation is an important component of water balance and heat balance, which plays an important role in the changes of the ecological environment [5]. Atmospheric precipitation is an important climatic resource, and its interannual and long-term changes have a significant impact on China's social and economic life [6], and also have a direct impact on the operation and storage capacity of reservoirs [7]. Therefore, it is very important to study the characteristics of evaporation and precipitation changes and predict their trends.

Climate change and human activities affect each other, and also have a great impact on the hydrological cycle. Therefore, scholars at home and abroad conducted a comprehensive study of climate changes [8-9]. The studies have found that changes in the water area caused by the storage of the reservoir will have an impact on the surrounding natural climate [10-12]. Typical large reservoirs such as the Three Gorges Reservoir have an impact on the surrounding temperature, evaporation and
precipitation [13-14]. Miyun Reservoir, as the largest reservoir in the Beijing-Tianjin-Tangshan region, has a strong local climate effect [15].

The Xiaolangdi Reservoir is a large water conservancy hub on the main stream of the Yellow River and has a great effect on the climate of the basin. At present, there are abundant studies on the climate, meteorology, and ecological impacts of the storage and operation of the Xiaolangdi Reservoir [16-20], but the years of meteorological data used in the research on the changes of evaporation and precipitation in the watersheds around the Xiaolangdi Reservoir are relatively short, and there is little research on the impact of climate change caused by reservoir storage on the surrounding areas.

This paper uses the evaporation and precipitation data of Xiaolangdi Reservoir and surrounding meteorological stations to study the changing trend of evaporation and precipitation in the area around Xiaolangdi, analyze the impact of water storage projects on climate and the impact of climate change on the surrounding area and the operation and scheduling of reservoirs. Then use the ARIMA model to fit and predict the evaporation and precipitation, which aims to develop the climatic resources of the watershed better, so as to optimize the functions and benefits of the reservoir. The research is of great significance to the rational operation of reservoirs, flood prevention, disaster reduction, and water resources planning and management [21].

2. Data and methods

2.1. Data sources and partitions
Select 5 meteorological observatories in Jiyuan, Mengjin, Xin'an, Mianchi and Yuanqu located in the submerged area of Xiaolangdi Reservoir as the reservoir area. Arithmetically average the climate data of these 5 meteorological observatories to represent the average climate situation of the reservoir area. Select 8 meteorological observation stations in Mengzhou, Yanshi, Gongyi, Wenxian, Boai, Yiyang, Yichuan and Yangcheng, which are not more than 80km away from the reservoir. Arithmetically average the climate data to represent the average climate around the reservoir. The geographical distribution of each site is shown in Figure 1.

![Figure 1. The geographical location of the Xiaolangdi Reservoir area and surrounding meteorological stations](image)

Select 32-year monthly meteorological monitoring data from 1982 to 2013, including precipitation and evaporation. In order to analyze the changes and differences in the climatic factors of the Xiaolangdi Reservoir before and after water storage, taking the reservoir closure year 1997 as the critical point, the 32-year meteorological data is divided into two periods, including the pre-storage period (1982-1997) and the post-storage period (1998-2013).
2.2. Analysis method

1) Linear propensity estimation method

In order to analyze the change trend of meteorological elements $x$ with the time series $t$ during $n$ years, a linear regression equation with the unary between $x_i$ and $t_i$ can be established:

$$x_i = a_i + b_i t_i \quad (i = 1, 2, \ldots, n)$$

(1)

$b_i$ represents the changing rate of $x$ with $t$ and $10b_i$ is defined as the climate propensity rate [22].

2) Cumulative anomaly method

The anomaly is the difference between the meteorological element value and its average value, and the cumulative anomaly is the accumulation of the anomaly. The cumulative anomaly curve can reflect the continuous change trend of the variable in a certain time range.

3) Mann-Kendall mutation test

The M-K mutation detection method can determine the possible mutations in the climate sequence, and can determine the occurrence time, and the significance level can determine the critical line. The moment corresponding to the intersection between the two curves $U_F$ and $U_B$ at the 0.05 significant horizontal line is the moment when the meteorological elements change suddenly. If the curve exceeds the significant horizontal line, it is considered that the rising or falling trend is significant [23-24].

4) Anomaly percentage comparison method

Through the net impact percentage, the trend of the reservoir during the 16 years before and after storage can be analyzed. The formula can be expressed as:

$$\text{Net impact percentage} = \frac{X_2 - X_1}{X_1} \times 100\%$$

(2)

Among them, $X_1$ is the average value of evaporation or precipitation in the 16 years before water storage. $X_2$ is the average value of evaporation or precipitation in the 16 years after water storage [16].

5) ARIMA model

ARIMA means Autoregressive Integrated Moving Average model, its principle is to use random sample data sequence build a prediction model based on autocorrelation analysis. ARIMA model is suitable for non-stationary random sequence prediction. Evaporation and precipitation have seasonal fluctuations, so the multiple seasonal ARIMA model $ARIMA(p,d,q)(P,D,Q)_S$ can be used for data’s fitting and prediction [25]. The formula of the model is:

$$(1 - B)^d(1 - B^S)^D X_t = \frac{\theta(B) \theta_s(B)}{\phi(B) \phi_s(B)} \varepsilon_t$$

(3)

3. Results and discussion

3.1. Trends in evaporation and precipitation

1) Annual trend of evaporation

The average evaporation in 32 years of Xiaolangdi Reservoir area is 1997.5mm. The analysis of the change trend of annual evaporation shows that the annual evaporation generally shows a downward trend (Figure 2), which is consistent with the obvious downward trend of annual evaporation of typical semi-humid and semi-arid areas in central China in the past 40 years [26].
Figure 2. Variation curve of annual evaporation in reservoir area

The broken line of annual evaporation in the reservoir area shows that the maximum evaporation occurred in 1987, which was 2023.08mm, and the minimum evaporation occurred in 2004, which was 1287.02mm. The difference between the maximum and minimum was 736.06mm. The regression equation shows that the climatic tendency rate of annual evaporation is -81.1mm / 10a.

The cumulative anomaly of the annual evaporation (Figure 3) shows that the annual evaporation of the reservoir area shows an upward trend from 1984-1987 and 1990-1997, and shows a downward trend from 2001-2013.

Figure 3. Cumulative anomaly of annual evaporation in reservoir area

MK mutation detection of annual evaporation (Figure 4) shows that the UF and UB curves intersect in 2001, the intersection point is between the critical line, and the UF value is less than 0, indicating that the sudden change in annual evaporation decreased in 2001. The UF curve exceeded the line of 0.05 significant level after 2005 and exceeded the line of 0.01 significant level after 2009, indicating that the annual evaporation of the reservoir area showed a significant downward trend. This result shows that the impoundment significantly reduces the evaporation in the reservoir area.
2) Annual trend of precipitation

The average precipitation in Xiaolangdi Reservoir area for 32 years is 607.7mm. The maximum precipitation in 32 years was 1035.62mm in 2003, and the minimum precipitation was 309.40mm in 1997. The fold line and fitting result of the annual precipitation in the reservoir area (Figure 5) show that the downward trend of annual precipitation over years is not obvious and has a large fluctuation range.

The regression equation of annual precipitation is obtained through linear regression. The equation shows precipitation’s climate tendency rate is -15.1mm / 10a, and the correlation coefficient is very small, indicating that the correlation between annual precipitation and time in the reservoir area is relatively low, and the linear relationship between the two is poor.

The cumulative anomaly of annual precipitation in the reservoir area (Figure 6) shows that the annual precipitation in the reservoir area shows an upward trend in 1982-1985 and 2002-2006, shows a downward trend in 1990-2001 and 2007-2010.
The MK mutation detection of the annual precipitation in the reservoir area (Figure 7) shows that the annual precipitation’s UF curve is below 0 in general, and in most periods the curve does not exceed the significance level of 0.05 confidence line, which means the annual precipitation shows a downward trend and the downward trend is not obvious. There are many intersections of UF and UB curves. After analysis, the annual precipitation decreases suddenly in 2003 and 2011.

The analysis of the peak point of the change curve of evaporation and precipitation (Figure 2 and Figure 6) shows that the annual evaporation of the reservoir area in 1997 is relatively high, preceded only by 1987 in the study period, and the annual precipitation is the lowest, so the available water resources are relatively scarce in 1987. The annual evaporation in 2003 is the lowest and the annual precipitation is the largest, which means that the available water resources were abundant. The historical relevant data corresponding to the Xiaolangdi watershed shows that the midstream of the Yellow River was extremely dry in 1997, and there was a phenomenon of interruption. For the problem of the outflow in the Yellow River Basin, the Xiaolangdi Reservoir has strengthened its drought resistance after the construction, appropriately increased the flood limit level to store water in advance, and brought forward the later flood season to late August. The flood storage during the flood season increased the storage capacity of the reservoir and eased the phenomenon of tight water supply in the lower Yellow River [27]. In 2003, due to the impact of heavy rainfall, the Yellow River Basin experienced the largest amount of floods since 1982 and the longest-lasting autumn floods. However, the scientific regulation and the
storage work of Xiaolangdi Reservoir has effectively reduced the peak flow and downstream flood control pressure.

3.2. Impact of Xiaolangdi Reservoir on climate

1) Impact of reservoir water storage on evaporation

Before storage, the average annual evaporation of the reservoir area is 1763.3mm, and after storage the average annual evaporation is 1583.8mm. According to the trend analysis of the annual evaporation in the reservoir area (Figure 8), it can be seen that the annual evaporation before storage is slightly increased, and the climate tendency rate is 80.8mm / 10a. After storage, the annual evaporation became a weak decreasing trend, and the tendency rate of climate is -56.2mm / 10a. The results show that after the storage of the reservoir, the evaporation in the reservoir area decreases, and the variation trend changes from a slight increase to a slight decrease. T-test analysis was performed on the annual evaporation of the reservoir area before and after storage, and the result is p=0.001, indicating that there is a significant difference in the evaporation before and after storage. As a result, the storage of water in the reservoir can significantly reduce the evaporation. Some studies have found that the storage of water in the reservoir increases the water area and the evaporation of the reservoir, also increases the air humidity near the reservoir by more than 1% [14], which causes a reduction in evaporation in the reservoir area and surrounding areas.

![Figure 8. Change curve of annual evaporation before and after storage](image)

To a certain extent, the reduced evaporation can reduce the impact of climate factors such as rising temperature and decreasing precipitation on runoff. At the same time, the reduction of evaporation is helpful to reduce the loss of water in the reservoir, and it is conducive to the work of the reservoir's water storage and drought resistance, but it is not conducive to the maintenance of the reservoir's water.

To compare the annual evaporation more intuitively before and after storage in the reservoir area and surrounding areas, the annual average evaporation before and after storage and the percentage of its net impact are calculated. The results are shown in Table 1. Table 1 shows that water storage of the reservoir plays a role in reducing evaporation within a certain range. Before the storage of the reservoir, the average annual evaporation of the reservoir area was significantly higher than that of the surrounding area. After storage, the evaporation volume of the reservoir area decreased significantly, and the gap with the surrounding evaporation volume was reduced to basically the same. The annual evaporation of the reservoir area after water storage decreases by 10.18% compared with that before water storage, and the decline is significant. Among them, Mengjin has the largest decline, which is 25.15%. The annual evaporation of the surrounding areas has decreased by 3.15%, which is smaller than the reservoir area. Among them, Yangcheng has the largest decrease of 17.40%, but the annual evaporation of other
surrounding stations’ changes was small, which are about 5%. The result shows that the influence range of Xiaolangdi Reservoir’s water storage on evaporation is limited in area.

Table 1. Average annual evaporation and net impact percentage before and after water storage

| Location          | Reservoir | Surrounding |
|-------------------|-----------|-------------|
| Average annual evaporation before storage /mm | 1763.32   | 1578.48     |
| Average annual evaporation after water storage /mm | 1583.83   | 1528.76     |
| Net impact percentage/% | -10.18%   | -3.15%      |

2) Impact of reservoir impoundment on precipitation

Before water storage, the average annual precipitation in the reservoir area was 597.6mm, and it became 627.0mm after water storage. The trend curve of annual precipitation in the reservoir area (Figure 9) shows that the climatic tendency rate of annual precipitation before storage is -185.0mm / 10a, showing a strong downward trend. After storage, the downward trend is significantly weakened and the climatic tendency rate is reduced to -46.3mm / 10a. The results show that the water storage of the reservoir has eased the downward trend of precipitation. The annual precipitation is basically stable at about 600mm. The years of extreme drought decrease, and the amount of available water resources increases, which has a positive impact on production and living, also the ecological environment.

Calculate the precipitation in the reservoir area and the surrounding area to obtain the average annual precipitation before and after the reservoir impoundment and its net impact percentage (Table 2). The average annual precipitation in the reservoir area before storage is 597.62 mm, and the precipitation in the reservoir area after storage is 626.97 mm, with an increase of 4.91%. The largest increase in a station in the reservoir area is Jiyuan, which is 10.2%. The following station is Yuanqu, with an increase of 6.77%. The average of annual precipitation in the surrounding area is 595.69 mm, and after storage it becomes 574.60 mm, with a decrease of 3.54%. Among them, the precipitation in Yichuan has the biggest decline of 9.87%. Before the impoundment, the annual precipitation in the reservoir area and the surrounding area was basically the same. But after impoundment, the annual average precipitation in the reservoir area increased slightly and the surrounding precipitation decreased slightly, which cause regional precipitation imbalance.

Figure 9. Change curve of annual precipitation before and after storage
Table 2. Average annual precipitation and percentage of net impact before and after water storage

| Location          | Reservoir | Surrounding |
|-------------------|-----------|-------------|
| Average annual evaporation before storage /mm | 597.62    | 595.69      |
| Average annual evaporation after water storage /mm | 626.97    | 574.60      |
| Net impact percentage/% | 4.91%     | -3.54%      |

3.3. Prediction of changes in evaporation and precipitation

1) Prediction model of evaporation changes

Predict the future evaporation change according to the climate characteristics after the construction of the reservoir, and the monthly evaporation from 1998 to 2012 in the reservoir area is used as the original data for modeling, and the optimal model is determined to be ARIMA (0, 0, 1) (0, 1, 1)_{12}. Using this model to fit the monthly evaporation from 1998 to 2012, and predict the monthly evaporation of the reservoir area in 2013 (Figure 10), figure 10 shows that the difference between the predicted value and the actual value is small, and the actual value is basically within the 95% confidence interval of the predicted value. The analysis shows that the seasonal variation $R^2$ is 0.800, and the BIC value is 6.831, indicating that the model fits well. Using the actual value of the monthly evaporation in 2013 to analyze the prediction accuracy of the model, the results show that the seasonal change trend of the predicted value is approximately the same as the actual value.

Figure 10. Monthly evaporation results of monthly evaporation of reservoir area

The fitted model can be used to make short-term predictions for the evaporation of the reservoir area (Figure 11). The predicted annual evaporation trend of the reservoir in 2014-2015 is roughly the same as in previous years. The linear fitting equation of the predicted value indicates that the climatic tendency rate of evaporation in the reservoir area still maintains a weak downward trend.

Figure 11. Prediction results of monthly evaporation in 2014-2015
2) Prediction model of precipitation changes

The monthly precipitation data from 1998 to 2012 in the reservoir area is used as the original data to determine the model parameters, and the optimal model for fitting is ARIMA (0, 0, 1) (0, 1, 1)_{12}. Apply this model to fit the monthly precipitation from 1998 to 2012 and predict the monthly evaporation in the reservoir area in 2013 (Figure 12). Figure 12 shows that both the fitted value and the predicted value have the same trend as the actual value and the gap is small, so the fitting result is good, and it is reasonable and feasible to use this model to predict future prediction. The seasonal variation $R^2$ is 0.889, the steady $R^2$ is 0.897, and the BIC value is 6.928, which also shows that the model can fit properly.

![Figure 12](image-url)  
**Figure 12.** Monthly prediction results of monthly evaporation of reservoir area

Using the model to predict the precipitation in the reservoir area from 2014 to 2015 (Figure 13). The predicted monthly precipitation trend has a continuous trend, which is basically the same as in previous years. Through liner fitting, it can be concluded that the change in precipitation is still shows a weak upward trend.

![Figure 13](image-url)  
**Figure 13.** Prediction results of monthly precipitation in 2014-2015

4. Conclusion

This paper draws the following conclusions by analyzing the evaporation and precipitation data in the Xiaolangdi Basin:

(1) From 1982 to 2013, the annual evaporation and annual precipitation in the Xiaolangdi Reservoir area both showed a volatile downward trend. The annual evaporation decreased abruptly in 2001, and the annual precipitation decreased abruptly in 2003 and 2011.
(2) The variation trend of the evaporation in the reservoir area before storage was a small increase, and then became a small decrease after the storage. After the storage, the decrease in the annual average evaporation of the reservoir area was greater than the decrease around the reservoir. The downward trend of precipitation in the reservoir area after the storage was significantly weakened compared with the trend before the storage. The annual precipitation in the reservoir area increased slightly after the storage and the surrounding precipitation decreased slightly. It shows that the storage of the reservoir has an impact on evaporation and precipitation, but the impact range is limited.

(3) Establish a reasonable ARIMA model to fit and predict the evaporation and precipitation of the Xiaolangdi Reservoir area. The verified model has good applicability and feasibility. It is predicted that the evaporation and precipitation are both sustained in annual changes and still maintain the trend of seasonal variation. The future evaporation will show a weak downward trend, and the precipitation will show a slight upward trend.

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