Statistical Analysis of Temporal Characteristics of Natural Runoff in Golmud River Basin

Yiwei Zhen¹, Shuguang Liu¹*, Zichen Hu¹ and Jiyu Liang¹

¹Department of Hydraulic Engineering, College of Civil Engineering, Tongji University, Shanghai, 200092, China
²liusgliu@tongji.edu.cn

Abstract: Based on the 45-year natural runoff time series from 1956 to 2000 of Golmud hydrological station, the control station of Golmud River basin, the inter-annual variation characteristics involving tendency, periodicity and abrupt change and intra-annual distribution of runoff were researched by using the linear tendency estimate method, cumulative departure method, Mann-Kendall method, Morlet wavelet analysis method, Yamamoto method and Pettitt method, combined with the analysis of annual average distribution process and complete adjustment coefficient. The results indicate that the overall inter-annual fluctuations of the runoff in the Golmud Basin are relatively small, and the overall annual runoff shows a significant increasing trend. After the abrupt change occurred in 1966, the runoff increased significantly. The variation of runoff has 3-year, 6-year and 18-year periods, and the 6-year period is especially obvious. Furthermore, there is a change rule of wet and dry with an 8-year alternation in the 18 years periodic variation. The intra-annual distribution of runoff is uneven, showing a "single peak" distribution, and the degree of unevenness tends to more concentrated.

1. Introduction
Golmud River is the second largest inland river in the Qaidam Basin and the primary water source for the largest city in the basin, Golmud City. In recent years, Golmud has developed rapidly economically and socially and has become an important base for the development of salinization and petrochemical resources in western China, which is of great strategic significance for the development of Qaidam Basin. Meanwhile, the urban comprehensive water use is gradually increasing, and the demand for the development and utilization of water resources in Golmud River basin is continuously increasing. At present, Chinese scholars have made some achievements in the study of water resources in the Golmud River basin¹⁻², but there are still relatively few studies on the change of natural runoff in Golmud River basin. Given this, this paper adopts a variety of hydrological analysis methods to comprehensively analyze the trend, periodicity, mutability and annual distribution characteristics of natural runoff of Golmud River from 1956 to 2000 and studies the change law of runoff, to provide scientific basis for the development and utilization, optimal allocation, disaster prevention and mitigation and sustainable development of water resources in the basin.

2. Study area and data
Golmud River originates from AkeTanQiqin Mountain, a branch of Kunlun Range. Its upper reaches are divided into three branches: east branch of Xueshui River, west branch of Najin River and south branch of South River. The three branches then converge to one river, which is called Golmud River. From south to north, it flows through Golmud City and finally into Dabusun Lake, with a total length
of 378.5 km and a total river basin area of 18648 km². Due to various reasons, the control stations of Golmud River- Golmud Station has experienced several changes of location. The runoff generation and confluence conditions of the first, second and third stations have not changed obviously, with no large tributaries in the section, thus the data of them can be combined to use. While the data of the fourth Golmud Station has been affected by upstream water conservancy projects development since the 1990s and needs to be restored for use. In this study, the restored natural runoff data from 1956 to 2000 for a total of 45 years was used to analyze the runoff law.

3. Analysis of inter-annual variation of natural runoff

3.1 Interannual and chronological variation characteristics

The annual runoff sequence of Golmud was analyzed by plotting the interannual variation process line (Figure 1) and calculating the characteristic value of annual runoff variation in each age (Table 1). By analysis, it is known that: (1) In terms of annual change, the average annual natural runoff of Golmud Station from 1956 to 2000 was 24.8 m³/s, the maximum average annual runoff 52 m³/s (the Year 1989), the minimum average annual runoff 17.4 m³/s (the Year 1963), the annual extremum ratio 2.99, the variation coefficient 0.23. The extremum ratio and variation coefficient were relatively small, which means that the interannual fluctuations of the annual runoff of the Golmud River are relatively small. (2) In terms of age change, the average annual runoff of Golmud Station in the 1950s, 1960s and 1990s was less than the average annual runoff, while the average annual runoff in the 1970s and 1980s was higher than the average annual runoff, among which the average annual runoff in the 1980s was the largest. The extremum ratio of natural runoff in each age was between 1.21-2.48, and the coefficient of variation was between 0.09-0.32. Both the maximum values of these two characteristic values appeared in the 1980s, which was mainly influenced by the annual runoff maximum value in 1989. (3) From the 5-year moving average process, it can be seen that the natural runoff in Golmud Station showed a less-more-less change process., which is about once every 20 years.

![Figure 1. Interannual variation of annual natural runoff in Golmud Station.](image)

| Year     | Average (m³/s) | Maximum (m³/s) | Minimum (m³/s) | Extremum ratio | Standard deviation | Coefficient of variation |
|----------|----------------|----------------|----------------|----------------|--------------------|--------------------------|
| 1956-1959| 22.0           | 24.1           | 19.9           | 1.21           | 1.97               | 0.09                     |
| 1960-1961| 22.2           | 29.7           | 17.4           | 1.71           | 3.84               | 0.17                     |
| 1970-1979| 25.6           | 32.9           | 19.5           | 1.69           | 4.25               | 0.17                     |
| 1980-1989| 29.2           | 52.0           | 21.0           | 2.48           | 9.27               | 0.32                     |
| 1990-1999| 23.9           | 26.4           | 20.9           | 1.26           | 2.07               | 0.09                     |
| 1956-2000| 24.8           | 52.0           | 17.4           | 2.99           | 5.71               | 0.23                     |
3.2 Trend analysis of runoff change

The linear trend estimation method and cumulative anomaly method\(^3\) were used to analyze the annual runoff trend change of Golmud Station. The linear trend rate of the natural runoff process of Golmud Station is positive (Figure 2), indicating that the annual natural runoff was increasing in statistical years. The cumulative anomaly process line shows that the runoff of Golmud Station was decreasing from the 1950s to the mid-1960s, and there was a rising trend from the mid-1960s to the early 1990s, then a slow decline after the early 1990s (Figure 2), which is consistent with the results of the 5-year moving average process.

At the same time, the Mann-Kendall test method\(^4\) was used for further quantitative analysis and research on the annual runoff evolution trend of Golmud Station. The results show that the Mann-Kendall (M-K) test values of the annual and monthly runoff are all positive (Figure 3), indicating that the annual runoff of the station was increasing, which is consistent with the previous qualitative analysis results. And the annual runoff series passed the test of the confidence level of 90%, indicating a significant increasing trend. In the runoff series of each month, the runoff in February, March, May and July passed the 90% confidence test, and the runoff in March passed the 99% confidence test. Thus, the runoff variation trend of Golmud Station in February, March, May and July has significantly increased, among which the increasing trend was the most obvious in March, while the increasing trend of other months was not significant.

3.3 Periodic analysis of runoff changes

In order to identify the periodicity of the natural runoff series of Golmud Station, the Morlet wavelet method\(^5\) was used to analyze the annual natural runoff of Golmud Station on multiple time scales and reveal the regularity of its periodic change. The time-frequency of wavelet coefficients real component of the wavelet transform was analysis to identify the runoff period. In the contour map of the real part of the wavelet transform (Figure 4), the solid line indicates that the real component of the corresponding wavelet coefficients is positive, that is, the runoff increases, while the dotted line indicates that the real component of the corresponding wavelet coefficients is negative, that is, the runoff reduces. In the wavelet variance diagram (Figure 5), the periodic variation law can be found according to the distribution relation of the periodic oscillation intensity of the runoff series over time.

The natural runoff of Golmud Station has obvious features of time-cycle variation, with periodic fluctuations at different scales of 2-year ~ 3-year, 5-year ~ 7-years and 17-year ~ 19-year(Figure 4), and the periodic oscillations show complex nested structures from large to small. On the small-scale periodic 2-year ~ 3-year and 5-year ~ 7-year, wet and dry changed violently alternately, and the fluctuation intensity generally increased first and then decreased. On the large-scale periodic 17-year ~ 19-year, the change of wet and dry is relatively stable, and it changes alternately once every eight
years. There are three low-water periods (1958-1966, 1976-1983 and 1993-2000) and two high-water periods (1967-1975 and 1984-1992).

It can also be further identified that the annual natural runoff in Golmud Station has three maximum values at 3-year, 6-year, and 18-year, with the maximum value at 6-year (Figure 5). The three peaks correspond to three periods of annual natural runoff variation, of which 6-year is the main period.

3.4 Shift analysis of runoff changes

Influenced by various factors such as natural changes and human activities, it is often difficult to ensure the accuracy of results by adopting a single method. In this paper, the Mann-Kendall test, Yamamoto method and Pettitt method were used to identify the abrupt change points of annual natural runoff in Golmud Station.

The abrupt change analysis of the natural runoff series of Golmud Station was carried out by the Mann-Kendall method\(^6\), the results of which presented in figure 6. Except 1962-1966, the UF curve was all greater than 0, indicating that the annual natural runoff of the Golmud river was basically in an increasing trend. The significance of the UF value of 1975 ~ 1994 was beyond 0.05, indicating a significant increase, which was consistent with the previous trend analysis results. Within the 0.05 confidence level limit, the UF and UB curves intersect at three points in 1958, 1960, and 1966, respectively, indicating that the annual runoff series of Golmud Station may have abrupt change at these three points. Combined with the case that the UF value exceeds the significant level, it can be determined that the annual natural runoff shift in 1966 and has increased significantly since the 1970s.

The Yamamoto method\(^7\) was also used to diagnose and verify the abrupt change point of annual natural runoff change in Golmud Station. According to relevant literature and multiple experiments, the optimal sample length of the two sub-sequences divided by the Yamamoto method was 5, and then the signal to noise ratio (SNR) of the Yamamoto method was calculated (See figure 7). According to the calculation results, the maximum SNR of the runoff series appeared in 1966, which was 1.23, greater than 1.0, which proved that 1966 was the abrupt change point of the natural runoff of the station.

Besides, the Pettit method\(^8\) was adopted to further analyze and verify the abrupt change point of the annual runoff series of Golmud Station. As the calculation results of the Pettit method show (Figure 8), the maximum test statistic 275 appeared in 1966, that is, 1966 was the possible abrupt change point of the series. The P value of this point was calculated to be 0.015, less than the critical value of 0.5, confirming that the change point of annual natural runoff series appeared in 1966.

Through comprehensive diagnosis and analysis, it was determined that there was a mutation in the annual natural runoff sequence of Golmud Station in 1966, and the runoff increased significantly since 1966.
4. Analysis of annual runoff distribution

4.1 Analysis of distribution process within the year

In order to grasp the occurrence law of flood, drought and other disasters and provide the basis for water allocation and water supply for industry and agriculture, this article analyzed the annual runoff distribution characteristics of Golmud Station by drawing the annual runoff distribution process of Golmud Station (Figure 9). As this figure shows, the annual runoff distribution of Golmud Station is uneven, showing a "single peak" distribution. The runoff during the flood season (June to October) accounts for 55.2% of the annual total, mainly concentrated in July and August, accounting for 27.4% of the annual runoff.

4.2 Analysis of distribution characteristics within a year

The annual distribution unevenness of runoff in Golmud Station was quantitatively analyzed by using the completed adjustment coefficient method\cite{9}. The completed adjustment coefficient (Cr) of the annual runoff is between 0.078 and 0.348 (See figure 10), with a relatively large amplitude of variation. The maximum value appeared in 1989 and the inhomogeneity within the year is relatively large. Combined with the linear trend line, the completed adjustment coefficient shows an upward trend, and the overall runoff distribution tends to be more concentrated.
5. Conclusions

With the various time series analysis methods, based on the 45-year natural runoff data of Golmud Station, the representative station of the Golmud River in Qaidam Basin, the inter-annual variation of the natural runoff of the river and its distribution characteristics during the year were analyzed. The main conclusions are as follows:

(1) According to the analysis of extreme ratio and coefficient of variation, the overall fluctuations of the inter-annual runoff variation in the Golmud Basin was relatively small. Influenced by the annual runoff maximum value in 1989, the fluctuation range of runoff in the 1980s was relatively large, while that in other ages were relatively small, and the intergenerational variation of runoff was generally stable. The result of the 5-year moving average analysis shows that the annual runoff of Golmud Station presented a change process between high and low flow once every 20 years in the statistical period.

(2) The natural runoff of the Golmud River exhibits an increasing trend as a whole. The results of the Mann Kendall test show upwards in the natural runoff trend of Golmud station on the scale of month and year, among which the annual runoff and the runoff in February, March, May and July increase is significant.

(3) The natural runoff of Golmud Station has the characteristics of multi-time scale evolution. According to the wavelet analysis, the annual runoff has 3-year, 6-year and 18-year periods. The periodic change is a complex nesting structure from large to small. On the small-scale period, the runoff changed drastically between abundance and drought. On the large-scale period, the runoff changed relatively lightly between abundance and drought, with three partial dry periods and two partial abundant periods.

(4) Based on the comprehensive judgment of the Mann-Kendall test, Yamamoto method, and Pettitt method, the annual natural runoff series in Golmud Station abrupt changed significantly in 1966, and the runoff increased significantly in the 1970s.

(5) The distribution of the Golmud River runoff is relatively uneven throughout the year, showing a ”single peak” distribution, and the flood season accounts for a large proportion, mainly concentrated in July and August.

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