Upstream Runoff Variation and Prediction Analysis of the Shule River (Postprint)

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Abstract

Using monthly runoff data from the Changmabao hydrological station in the upper Shule River basin from 1956 to 2020, eight characteristic indicators of intra-annual runoff distribution including the Gini coefficient and Lorenz asymmetry coefficient were selected. Combined with various statistical methods such as M-K test and R/S analysis, the evolution patterns of runoff in the upper Shule River were comprehensively analyzed from both intra-annual and inter-annual perspectives. The results show that: (1) The intra-annual distribution of runoff in the upper Shule River exhibits a unimodal pattern, mainly concentrated in the flood season. Except for the absolute variation amplitude (ΔR), all other intra-annual distribution indicators show a decreasing trend, indicating that the intra-annual distribution is gradually becoming more uniform; (2) The annual runoff shows an overall increasing trend, especially after the abrupt change in 1997, the tendency rate increased, with the average annual runoff increasing by 59% compared to before the change; (3) Runoff in spring, summer, autumn, and winter all show an overall upward trend, with the largest tendency rate in summer and the smallest in winter. After the abrupt change in the 1990s, the average runoff in all seasons increased significantly compared to before the change, with the magnitude of change ranked as: autumn (76%) > winter (74%) > summer (58%) > spring (45%); (4) Both annual and seasonal runoff in the upper Shule River have multi-temporal characteristic scale cycles, with the first primary cycle being 56 a for all; (5) Predictions for runoff from 2022 to 2024 indicate that runoff in the upper Shule River will continue to show an upward trend in the next three years. The research results provide a scientific basis for accurately understanding the variation patterns and characteristics of runoff in the upper Shule River, and offer guidance for the sustainable development and utilization of water resources in the Shule River basin as well as for studying runoff variation patterns in similar inland river basins.

Full Text

Preamble

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Runoff Variation and Prediction Analysis in the Upper Reaches of the Shule River

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Abstract: Using monthly runoff data from the Changmabao Hydrological Station in the upper reaches of the Shule River from 1956 to 2019, this study selected intra-annual distribution characteristic indicators such as the Gini coefficient and Lorentz asymmetry coefficient. Combined with multiple statistical methods including the M-K test, sliding t-test, linear tendency estimation, R/S analysis, and wavelet analysis, the evolution patterns of runoff in the upper Shule River were comprehensively analyzed from both intra-annual and inter-annual perspectives. The results show that: (1) The intra-annual distribution of runoff in the upper Shule River exhibits a unimodal pattern, concentrated mainly in the flood season. Except for the absolute variation amplitude, all other intra-annual distribution indicators show a decreasing trend, indicating that the intra-annual distribution is gradually becoming more uniform. (2) Annual runoff shows an overall increasing trend, particularly after the abrupt change in 1997, with the tendency rate increasing and the average annual runoff rising by 59% compared to the pre-mutation period. (3) Runoff in spring, summer, autumn, and winter all show upward trends, with the largest tendency rate in summer and the smallest in winter. After the abrupt change in the 1990s, the average runoff in each season increased significantly compared to before, with the magnitude of change ranking as: autumn (76%) > winter (74%) > summer (58%) > spring (45%). (4) Both annual and seasonal runoff in the upper Shule River exhibit multi-time-scale periodic characteristics, with the first main cycle being 56 years for all. (5) Runoff predictions for 2022–2024 indicate that runoff in the upper Shule River will continue to increase in the coming years. These findings provide a scientific basis for accurately understanding runoff variation patterns and characteristics in the upper Shule River, and offer guidance for sustainable water resource development and utilization in the Shule River Basin as well as for studying runoff variation patterns in similar inland river basins.

Keywords: runoff seasonal distribution; inter-annual variation; runoff forecast; upper reaches of the Shule River

Introduction

Runoff, as a crucial component of water system structure, exhibits significant correlation with climatic factors. Precipitation, temperature, and evaporation alter the water and energy exchange and transmission processes between land surface and atmosphere, thereby directly changing runoff processes and causing temporal and spatial redistribution of water resources. This intensifies flood or drought disasters in certain regions, changes available water resources, and further impacts ecosystems, natural resources, extreme climate events, and human society. Runoff variation can lead to changes in water resource quantity and water ecosystem structure, posing severe challenges to rational water resource planning and efficient management. Therefore, comprehensive analysis of runoff evolution patterns under changing environments holds practical significance.

Previous scholars have conducted extensive research on typical basins to clarify runoff evolution characteristics under environmental changes. Sun Jialan et al. systematically analyzed multi-year runoff variation characteristics in the Yangtze River Basin using linear tendency estimation, M-K test, and wavelet analysis. Xing Zhenxiang et al. analyzed runoff variation characteristics in the Naoli River Basin using linear tendency and M-K test methods. Most of these studies focused on inter-annual variation characteristics. However, with climate warming and intensified human activities, runoff distribution patterns have changed significantly, leading to issues such as altered intra-annual distribution, glacier retreat, and downstream river drying. The intra-annual distribution of runoff is closely related to rational water resource utilization and regional flood and drought prevention. Some scholars have investigated intra-annual distribution patterns: Tu Xinjun et al. examined intra-annual variation characteristics of runoff in the Dongjiang River using four indicators including concentration degree, concentration period, non-uniformity coefficient, and extreme ratio; Liu Yongting et al. quantitatively evaluated intra-annual distribution uniformity of runoff in the upper Huaihe River using the Gini coefficient and Lorentz asymmetry coefficient. Overall, runoff variation includes both quantitative and structural aspects, with intra-annual distribution being a key structural characteristic.

The Shule River Basin is one of the three major inland river basins in Gansu Province and an important water source area in the Hexi region of Gansu. Runoff variation in its upper reaches affects sustainable water resource utilization in the middle and lower reaches. Many scholars have studied runoff variation patterns in the upper Shule River. Zhang Wenchun analyzed trend characteristics of annual average runoff based on data from Changmabao Hydrological Station. Zhang Xiaoxiao et al. investigated intra-annual distribution patterns of runoff in the upper Shule River using indicators such as intra-annual non-uniformity coefficient and variation amplitude. While previous studies comprehensively analyzed intra-annual variation, trend, and mutation characteristics, further supplementation and improvement are needed in indicator selection and characteristic analysis methods for intra-annual distribution. Therefore, this study examines runoff variation from both intra-annual and inter-annual perspectives, using eight intra-annual distribution characteristic indicators including the Gini coefficient, Lorentz asymmetry coefficient, concentration degree, concentration period, non-uniformity coefficient, complete adjustment coefficient, relative variation amplitude, and absolute variation amplitude. Combined with statistical methods such as M-K test, sliding t-test, linear tendency estimation, R/S analysis, and wavelet analysis, this study comprehensively investigates intra-annual distribution, trend, variability, persistence, and periodicity of runoff in the upper Shule River. Additionally, grey prediction models are employed to forecast future annual runoff, systematically studying temporal variation patterns of runoff to lay a foundation for further clarifying influencing factors of runoff variation in inland river basins under environmental changes.

1. Study Area and Data

1.1 Study Area Overview

The Shule River Basin is one of the three major inland river basins in Gansu Province, with the Changma Reservoir and Shuangtabao Reservoir serving as boundaries between the upper, middle, and lower reaches. The upper reach of the Shule River has a total length of 328 km and a drainage area of 10,961 km^2. It belongs to a dry, cold, windy plateau continental climate zone, with extensive distribution of glaciers, snow cover, and frozen soil. The average annual runoff volume is 10.28$×10^{8}$ m^3. The Changmabao Hydrological Station is located in this region (Fig. 1).

1.2 Data Sources

Monthly runoff data from 1956 to 2019 were obtained from the Changmabao Hydrological Station, a control station in the upper Shule River operated by the Jiuquan Hydrological Station of Gansu Province. In this study, March-May is defined as spring, June-August as summer, September-November as autumn, and December-February as winter.

1.3 Methods

1.3.1 Intra-Annual Distribution Analysis Methods To quantitatively analyze runoff evolution patterns in the upper Shule River, based on the percentage of monthly (or seasonal) runoff to annual runoff, eight intra-annual distribution characteristic indicators were selected: intra-annual non-uniformity coefficient (C_v), complete adjustment coefficient (C_r), concentration degree (C_d), concentration period (C_n), relative variation amplitude (C_m), absolute variation amplitude (R), Gini coefficient (G_i), and Lorentz asymmetry coefficient (S). These indicators analyze intra-annual variation from different perspectives.

1.3.2 Inter-Annual Variation Analysis Methods Inter-annual variation characteristics including persistence, abrupt change, trend, and periodicity were analyzed using the Hurst index, M-K test, sliding t-test, linear tendency estimation, and wavelet analysis methods.

1.3.3 Runoff Prediction Analysis Methods The grey prediction model is a single-series prediction model superior to linear regression, with its sequence expression being a first-order linear differential equation. Due to the mutational nature of runoff variation, the GM(1,1) grey prediction model was proposed to improve prediction accuracy. The calculation principle involves: (1) determining the average cycle period T of the sequence using R/S analysis; (2) establishing a grey prediction model with T as the research cycle to predict N-year runoff; and (3) conducting residual tests on the model. If passed, the model continues to predict runoff for subsequent years. Additionally, the ARIMA model, a combination of autoregressive integrated moving average model, was used. ARIMA is denoted as ARIMA(p,d,q), where p is the number of autoregressive terms, d is the differencing order for sequence stationarity, and q is the number of moving average terms.

2. Results and Analysis

2.1 Intra-Annual Distribution Characteristics

2.1.1 Intra-Annual Distribution Pattern The Shule River Basin is a typical inland river basin, with its main supply sources being precipitation and glacier melt. As shown in Fig. 2, runoff at Changmabao Station exhibits a unimodal distribution, remaining low in winter. In spring, as temperature rises and precipitation and snowmelt increase, runoff shows an upward trend. During the summer flood season, runoff increases sharply, reaching its maximum in July. In autumn, as temperature decreases, runoff shows a slow downward trend, returning to normal by December. Combined with Fig. 2, runoff is concentrated in the flood season (June–September), accounting for 49.23%-53.29% of the multi-year average. The maximum monthly runoff appears in July for the 1950s–1980s and 2000s–2010s, accounting for 23.74%-27.97% of the multi-year average, while for the 1960s–1970s and 1990s, it appears in August, accounting for 24.20%-26.60%.

Table 1 shows that the multi-year average runoff in the upper Shule River is 10.28\$×10^{8}\$ m^3, with each decade showing continuous increases. The 2010s runoff was more than double that of the 1950s. The overall trend is upward, with runoff concentrated in summer and autumn throughout the year. The specific seasonal ranking for each period is: summer (56.50%-62.91%) > autumn (17.60%-20.39%) > spring (11.41%-15.48%) > winter (7.25%-8.97%).

2.1.2 Intra-Annual Distribution Uniformity Affected by climate change and human activities, the water cycle in the upper Shule River has undergone obvious seasonal changes, leading to altered intra-annual distribution uniformity. Table 2 shows that the Gini coefficient, Lorentz asymmetry coefficient, concentration degree, concentration period, non-uniformity coefficient, complete adjustment coefficient, and relative variation amplitude all show decreasing trends at rates of $-0.015 \cdot (10a)^{-1}$, $-0.006 \cdot (10a)^{-1}$, $-0.006 \cdot (10a)^{-1}$, $-1.053 \cdot (10a)^{-1}$, $-0.006 \cdot (10a)^{-1}$, $-0.006 \cdot (10a)^{-1}$, and $-0.006 \cdot (10a)^{-1}$, respectively. The absolute variation amplitude also shows a decreasing trend when extreme values are excluded. These trends indicate that the intra-annual maximum and minimum monthly runoff differences are continuously decreasing, and the intra-annual distribution is becoming more uniform in terms of non-uniformity, concentration, and variation amplitude.

2.2 Runoff Persistence and Abrupt Change Analysis

The Hurst index can quantitatively characterize long-term correlation in time series, with its value indicating whether trend components exist. Table 3 shows that the Hurst index for annual runoff and seasonal runoff (spring, autumn, winter) is greater than 0.5, showing positive persistence. The Hurst index for summer runoff is also much greater than 0.5, indicating strong positive persistence and that future runoff in the upper Shule River will continue its upward trend.

Fig. 3 presents the R/S analysis results for annual runoff. The M-K test (Fig. 4) shows an intersection point within the 95% confidence interval at 1997, indicating this as the abrupt change point for annual runoff. The sliding t-test (Fig. 4) also identifies an abrupt change in annual runoff in the late 1990s. The cumulative anomaly of annual runoff (Fig. 5) shows a downward trend before 1997 and an upward trend afterward, with a rapid increase rate, confirming the mutation test results.

Table 3 shows that spring, summer, autumn, and winter runoff all passed the M-K test significance level, with abrupt changes occurring in the 1990s. After the abrupt change, the coefficient of variation for each season is smaller than before, indicating reduced variability, and the average runoff after mutation increased significantly compared to before, ranking as: autumn (76%) > winter (74%) > summer (58%) > spring (45%).

2.3 Runoff Trend Analysis

The multi-year average runoff in the upper Shule River is 10.28$\times10^{8}$ m^3, with a maximum of 17.44$\times10^{8}$ m^3 in 2018 and a minimum of 4.13$\times10^{8}$ m^3 in 1960. Table 4 shows that annual runoff increased significantly at a rate of 1.21$\times10^{8}$ m$^3 \cdot (10a)^{-1}$, passing the 0.01 significance level. After the abrupt change, annual runoff increased by 59% compared to before. Seasonal runoff also shows upward trends: summer has the largest tendency rate at 0.74$\times10^{8}$ m$^3 \cdot (10a)^{-1}$, followed by autumn at 0.20$\times10^{8}$ m$^3 \cdot (10a)^{-1}$, spring at 0.18$\times10^{8}$ m$^3 \cdot (10a)^{-1}$, and winter has the smallest increase at 0.09$\times10^{8}$ m$^3 \cdot (10a)^{-1}$.

2.4 Runoff Periodicity Analysis

Wavelet analysis reveals that annual runoff in the upper Shule River has three main cycles: 56, 22, and 12 years, with 56 years being the first main cycle. Fig. 7 shows that for the 56-year characteristic time scale, there are 4 wet-period centers and 3 dry-period centers corresponding to 1957, 1975, 1994, and 2013, and 1966, 1984, and 2003, respectively, experiencing 3 wet-dry transitions. At the 22-year scale, there are 2 wet-period centers and 2 dry-period centers with 9 transitions. At the 12-year scale, there are approximately 5 wet-dry transitions with frequent alternation.

Table 5 shows that all four seasons exhibit multiple time-scale periods. Spring’ s first, second, and third main cycles are 56, 22, and 12 years; summer’ s are 56, 22, and 12 years; autumn’ s first and second main cycles are 56 and 22 years; and winter’ s first main cycle is 56 years.

2.5 Runoff Prediction Analysis

Using measured annual runoff data from 1956–2019 for the upper Shule River, grey prediction models (GM(1,1) and improved GM(1,1)), and ARIMA models were constructed. With 2017–2019 as the validation period, 2022–2024 runoff was predicted (Table 6). Considering the prediction effects of all models, the comprehensive prediction values were used as the final predictions: 15.67$×10^{8}$ m^{3}, 15.49$×10^{8}$ m^{3}, and 15.53$×10^{8}$ m^{3} for 2022, 2023, and 2024, respectively.

3. Discussion

The upper Shule River is located in the Qilian Mountains with minimal human interference, and runoff shows an overall increasing trend. This study analyzed runoff evolution characteristics based on monthly runoff data from Changmabao Hydrological Station from 1956–2019. The results show that seasonal runoff in spring, summer, autumn, and winter all increased, with the highest increase in summer and the lowest in winter. Ding Hongwei et al., using Fourier-based spectral analysis, found that the 22-year periodic variation was most significant in the upper Shule River. This study, using wavelet analysis, found the 56-year cycle to be most significant. Different results may arise from varying study periods or methods, and runoff’ s random, mutational, and nonlinear characteristics contribute to these differences.

Previous studies on the upper Shule River have analyzed intra-annual variation, trend, and mutation characteristics, but this study supplements and improves the analysis by adding the Lorentz asymmetry coefficient to evaluate how different monthly runoff contributes to uniformity. All distribution indicators except absolute variation amplitude show decreasing trends, indicating increasingly uniform intra-annual distribution. This is mainly because rising temperatures increase runoff during dry seasons, regulating intra-annual distribution uniformity.

Grey prediction and ARIMA models were used to predict future annual runoff. The grey prediction model had the smallest relative error, but large errors can occur in mutation years. Considering runoff’ s periodicity, R/S analysis was used to determine cycle period T for grey prediction. However, grey prediction model accuracy decreases with stronger jumpiness and volatility. This study used univariate models like ARIMA, which predict based on runoff’ s own variation patterns without considering meteorological factors like precipitation and temperature, causing some error between predicted and measured values. Future research should develop multivariate prediction models.

4. Conclusions

Based on monthly runoff data from Changmabao Hydrological Station in the upper Shule River from 1956–2019, this study analyzed runoff variation characteristics. The main conclusions are:

(1) The Gini coefficient, Lorentz asymmetry coefficient, and other intra-annual distribution indicators show decreasing trends, indicating that intra-annual distribution is becoming more uniform. This is mainly due to temperature increases that enhance dry-season runoff, regulating intra-annual distribution uniformity.

(2) Annual and seasonal runoff experienced abrupt changes in the late 1990s. After mutation, average runoff increased by 59% annually, and by 45% in spring, 58% in summer, 76% in autumn, and 74% in winter compared to pre-mutation values. These increases are closely related to increased precipitation and temperature-induced glacier melt.

(3) Both annual and seasonal runoff in the upper Shule River exhibit multi-time-scale periodic characteristics, with the first main cycle being 56 years for all. The second main cycle is 22 years for annual, spring, and summer runoff.

(4) During the study period, annual and seasonal runoff in the upper Shule River showed upward trends. Comprehensive predictions indicate that runoff will continue to increase, with predicted values of 15.53$\times10^{8}$ m^3, 15.67$\times10^{8}$ m^3, and 15.49$\times10^{8}$ m^3 for 2022–2024.

References

[1] Sun Congjian, Chen Wei, Wang Shiyu. Stream component characteristics of the inland river basin of the Tarim Basin under regional climate change[J]. Arid Zone Research, 2022, 39(1): 113-122.

[2] Yang Pan, Liang Wei, Yan Jianwu, et al. Multi-scale analysis of water system structure changes in the Yellow River Basin[J]. Journal of Desert Research, 2021, 41(6): 223-234.

[3] Sun Jialan, Lei Xiaohui, Jiang Yunzhong, et al. Variation trend analysis of meteorological variables and runoff in upper reaches of Yangtze River[J]. Water Resources and Power, 2012, 30(5): 1-4.

[4] Pan B, Han M, Wei F, et al. Analysis of the variation characteristics of runoff and sediment in the Yellow River within 70 years[J]. Water Resources, 2021, 48(5): 676-689.

[5] Xing Zhenxiang, Liu Meixin, Fu Qiang, et al. Analysis of runoff variation and impacting factors in Naoli River Basin[J]. Transactions of the Chinese Society for Agricultural Machinery, 2015, 46(9): 178-187.

[6] Liu Zhibin, Huang Yue, Liu Tie, et al. Climate response of runoff variation in the source area of the Kaidu River[J]. Arid Zone Research, 2020, 37(2): 418-427.

[7] Liu Shuangshuang, Li Zhongqin, Zhang Hui, et al. Temporal inner-annual runoff variation in the typical glacier region of the eastern Tianshan Mountains, China[J]. Arid Zone Research, 2020, 37(6): 1388-1395.

[8] Wang Yujie, Qin Dahe. Influence of climate change and human activity on water resources in arid region of Northwest China: An Overview[J]. Climate Change Research, 2017, 13(5): 483-493.

[9] Chen Yaning, Li Zhi, Fan Yuting, et al. Research progress on the impact of climate change on water resources in the arid region of Northwest China[J]. Acta Geographica Sinica, 2014, 69(9): 1295-1304.

[10] Tu Xinjun, Chen Xiaohong, Zhang Lijuan, et al. Annual distribution of streamflow with different identifications of time intervals[J]. Ecology and Environmental Sciences, 2011, 20(1): 119-123.

[11] Liu Yongting, Xu Guanglai, Li Peng, et al. Study on runoff uniformity and variation in the upper reaches of Huaihe River Basin[J]. Research of Soil and Water Conservation, 2017, 24(5): 99-104.

[12] Chen Xianguang, Wang Long, Zhang Yulong. Study on change trend of annual runoff distribution in Longchuan River[J]. Journal of Yunnan Agricultural University (Natural Science Edition), 2011, 26(5): 712-716.

[13] Zhou Xiuping, Huang Weijun, Wang Wensheng. Runoff variation characteristics analysis for Guijiang River Basin[J]. Guangxi Water Resources & Hydropower Engineering, 2008, 37(1): 22-25, 39.

[14] Zheng Hongxing, Liu Changming. Changes of annual runoff distribution in the headwater of the Yellow River Basin[J]. Progress in Geography, 2003, 22(6): 585-590, 649.

[15] Li Hongyuan, Zhao Qiudong, Wu Jinkui, et al. Quantitative simulation of the runoff components and its variation characteristics in the upstream of the Shule River[J]. Journal of Glaciology and Geocryology, 2019, 41(4): 907-917.

[16] Yang Chunli, Lan Yongchao, Wang Ninglian, et al. Mountainous runoff changes and climate factors analysis of the Shule River Basin in 1958-2015[J]. Scientia Geographica Sinica, 2017, 37(12): 1894-1899.

[17] Niu Zuirong, Zhao Wenzhi, Liu Jinqi, et al. Study on change characteristics and tendency of temperature, precipitation and runoff in Weihe River Basin in Gansu[J]. Journal of China Hydrology, 2012, 32(2): 78-83, 87.

[18] Zhang Wenchun. Study on the change trend of runoff in the middle and upper reaches of the main stream of Shule River[J]. Ground Water, 2019, 41(2): 155-156, 211.

[19] Zhang Xiaoxiao, Zhang Yu, Xu Haojie. Changes of annual runoff distribution on the upper reaches of the Shule River[J]. Yellow River, 2014, 36(6): 58-60.

[20] Lan Yongchao, Hu Xinglin, Ding Hongwei, et al. Variation of water cycle factors in the western Qilian Mountain Area under climate warming—taking the mountain watershed of the main stream of Shule River Basin for example[J]. Journal of Mountain Science, 2012, 30(6): 675-680.

[21] Hou Kai, Lin Tao, Qian Hui, et al. Change characteristics and trend prediction of climate in Wugong Area[J]. Research of Soil and Water Conservation, 2017, 24(4): 252-258.

[22] Sun Dongyuan, Qi Guangping, Ma Yanlin, et al. Variation characteristics of runoff in the mainstream of Shule River[J]. Arid Land Geography, 2020, 43(3): 557-567.

[23] Niu Zuirong, Wang Qiyou, Sun Dongyuan, et al. Runoff variation characteristics of Taohe River Basin based on calculation of current runoff[J]. Arid Land Geography, 2021, 44(1): 149-157.

[24] Cao Zhenyu. Variation regularity of intra-annual runoff distribution in the upstream of the Muling River Basin[J]. Water Resources and Power, 2019, 37(1): 21-25.

[25] Niu Zuirong, Chen Xuelin, Wang Xueliang. Runoff variation characteristics of representative stations on mainstream of Bailongjiang River and trend prediction[J]. Journal of China Hydrology, 2015, 35(5): 91-96.

[26] Zhang Xiaoxiao. Variation Characteristics Analysis of Hydrometeorology Elements and Affecting Factors of Runoff in the Middle-Upper Reaches of the Bailong River[D]. Lanzhou: Lanzhou University, 2014.

[27] Liu Shu, Wang Yan, Hu Fengge. Discussion on residual error of grey prediction model[J]. Statistics & Decision, 2008, 14(1): 9-11.

[28] Ye Zhengwei, Yin Peng. Changes of precipitation concentration degree and precipitation concentration period in flood season in the Huaihe River Basin[J]. Research of Soil and Water Conservation, 2018, 25(5): 295-299.

[29] Cao Hui, Huang Qiang, Bai Tao, et al. Comparative analysis of runoff forecasting methods[J]. Yellow River, 2009, 31(9): 36-37.

[30] Chen Jianlong, Liu Yongfeng, Qian Ju, et al. Annual runoff inflow into Yuanyangchi reservoir prediction based on the combination of R/S analysis and GM(1,1) grey model[J]. Journal of Water Resources and Water Engineering, 2018, 29(5): 148-153, 158.

[31] Tang Qicheng, Chen Tianwen, Li Xiuyun. Concentration and monthly runoff of Chinese rivers: preliminary study during the concentration period[J]. Acta Geographica Sinica, 1982, 48(4): 383-393.

[32] Xu Wanling, Zhu Weihong, Zhang Jian, et al. Analysis on temporal inhomogeneity of runoff in Tumen River mainstream based on Lorenz Curve[J]. Bulletin of Soil and Water Conservation, 2015, 35(1): 128-132.

[33] Hu Caixia, Xie Ping, Xu Bin, et al. Variation analysis method for hydrologic annual distribution homogeneity based on Gini coefficient: a case study of runoff series at Longchun station in Dongjiang River Basin[J]. Journal of Hydroelectric Engineering, 2012, 31(6): 7-13.

[34] Jia Ling, Sun Dongyuan, Niu Zuirong, et al. Pattern of maximum and minimum temperature variation in Shule River Basin[J]. Research of Soil and Water Conservation, 2022, 29(1): 281-287.

[35] Huang Jichen, Lu Baohong, Fan Zhongli, et al. Analysis of annual distribution of precipitation and runoff and synchronism of their variation in Qingjiang Basin[J]. Journal of China Three Gorges University (Natural Sciences Edition), 2017, 39(6): 25-30.

[36] Li Fuxing. Study on Manas River Runoff Evolution Characteristics and Its Medium and Long-term Forecast Model[D]. Shihezi: Shihezi University, 2021.

[37] Li Fuxing, Chen Fulong, Cai Wenjing, et al. Multiscale runoff prediction based on the EMD combined model[J]. Earth Science Frontiers, 2021, 28(1): 428-437.

[38] Guo Shenglian, Guo Jiali, Hou Yukun, et al. Prediction of future runoff change based on Budyko hypothesis in Yangtze River Basin[J]. Advances in Water Science, 2015, 26(2): 151-160.

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