Postprint: Study on Runoff Variation Characteristics in the Tao River Basin Based on Runoff Naturalization

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Abstract

River runoff updating calculation constitutes the foundation for accurately reflecting regional water resources status and serves as a crucial basis for water resources planning and decision-making. Long-series runoff data from two representative hydrological stations (Lijiacun and Hongqi) in the Taohe River basin of Gansu Province were selected as baseline data. Based on restoration calculations, runoff updating calculations were performed for the Taohe River basin, and runoff variation characteristics were simultaneously investigated. The results indicate that: from 1956 to 2016, the multi-year average measured runoff at Lijiacun and Hongqi stations in the Taohe River basin was 39.52$ $\times 10^8 m^3 and 44.66 \times 10^8 m^3, respectively; the multi-$
$year average natural runoff after restoration was 39.69 \times 10^8 m^3 and 46.11 \times 10^8 m^3, respectively; the multi-$
$year average restoration water volume was 0.17 \times 10^8 m^3 and 1.45 \times 10^8 m^3, respectively; water consumption at the tu$
$year average natural runoff at Lijiacun and Hongqi stations was 31.76 \times 10^8 m^3 and 38.77 \times 10^8 m^3, respectively, rep$
m^3, respectively, corresponding to decreases of 20% and 15%. After updating to present conditions, the annual runoff at Lijiacun station exhibited a slight increasing trend, whereas the annual runoff at Hongqi station displayed a slight decreasing trend. Runoff demonstrated interdecadal characteristics of being below the multi-year average during the 1950s and from the 1970s to the 2000s, and above the average during the 2010s, with varying wet, normal, and dry conditions across different decades. The research findings provide fundamental support for water resources investigation and evaluation in the basin, and play a significant role in promoting efficient utilization and optimal allocation of water resources in the basin, as well as guiding integrated water resources management and socio-economic development in the region.

Full Text

Runoff Variation Characteristics of the Taohe River Basin Based on Current Runoff Calculation

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Abstract

Current runoff calculation is fundamental for accurately reflecting regional water resource conditions and serves as a critical basis for water resource planning and decision-making. This study selected long-term runoff data from Lijiacun and Hongqi hydrological stations in the Taohe River Basin of Gansu Province as the foundational dataset. Based on reduction calculations, current runoff calculations were performed for the Taohe River Basin, and the characteristics of runoff variation were analyzed. The results indicate that from 1956 to 2016, the multi-year average measured runoff at Lijiacun and Hongqi stations were 39.52×10^{8} m^3 and 44.66×10^{8} m^3, respectively. After reduction calculation, the multi-year average natural runoff values were 39.69×10^{8} m^3 and 46.11×10^{8} m^3, respectively, with average reduction water volumes of 0.17×10^{8} m^3 and 1.45×10^{8} m^3. Water consumption at both stations was primarily for agricultural irrigation. The mutation trends of natural runoff at the two stations were basically consistent, with mutation points occurring in 1990. After correction to current conditions, the multi-year average natural runoff at Lijiacun and Hongqi stations were 31.76×10^{8} m^3 and 38.77×10^{8} m^3, respectively, representing reductions of 7.04×10^{8} m^3 and 7.93×10^{8} m^3 compared to the reduced natural runoff. Following current calculation, the annual runoff at Lijiacun station shows a slight increasing trend, while Hongqi station shows a slight decreasing trend. Runoff exhibits distinct interdecadal characteristics, with the 1990s–2000s being above the multi-year average and different periods showing wet, normal, and dry states. These research results provide fundamental support for basin water resource investigation and evaluation, and are important for promoting efficient water resource utilization, optimal allocation, and guiding comprehensive water resource management and socio-economic development in the region.

Keywords: Taohe River Basin; natural runoff; current runoff calculation; variation characteristics

1 Introduction

Runoff represents a critical component of regional water cycles and water balance, serving as the primary element for regional water resource utilization and evaluation. Influenced by climate change and human activities, underlying surface conditions in river basins have undergone significant changes, leading to remarkable alterations in river runoff processes. River runoff reduction calculation forms the foundation of water resource evaluation and provides the essential basis for rational allocation and scheduling of limited water resources to serve production needs. Reduction calculations are divided into "forward reduction" and "backward reduction." Forward reduction refers to converting measured annual runoff series into so-called natural annual runoff series before large-scale water conservancy projects were constructed in the basin. Backward reduction refers to converting the natural annual runoff series of each representative station to annual runoff series under current conditions—that is, current runoff calculation. Forward reduction evaluation results reflect the natural state of water resources in a basin. However, with rapid socio-economic development and extensive construction of water conservancy projects, regional underlying surface conditions have changed substantially and cannot return to natural states, making these results unsuitable for direct application in water project planning, design, and decision-making. Current runoff calculation can truly reflect water conservancy project construction status and water resource utilization, providing technical support for scientific, rational allocation and sustainable development of regional water resources.

Numerous scholars have conducted reduction studies using various methods including projection pursuit, neural network models, and SWAT models for different regions. However, research on current runoff calculation remains relatively scarce. The Taohe River is the largest first-order tributary of the upper Yellow River in terms of water volume. Yet, with climate change and human activity impacts on the underlying surface, the Taohe River' s runoff has shown a significant decreasing trend over the past two decades. Traditional water resource evaluation and hydraulic engineering design typically involve reducing measured runoff series to natural conditions before conducting assessments or engineering design. Since climate change factors such as rising temperatures show no signs of reversal in the short term, and some water diversion projects within the basin (particularly those diverting water out of the basin) are permanent, this reduction approach inevitably creates an illusion of inflated water resources (natural runoff after reduction), seriously affecting scientific water resource allocation and development. For instance, downstream hydropower stations may fail to generate power at full capacity due to insufficient water inflow relative to design standards.

This study employs technical specifications from the third national water resource survey and evaluation, utilizing 1956–2016 runoff and areal average precipitation data from two hydrological control stations in the Taohe River Basin. Building upon traditional reduction calculations, this research focuses on exploring current runoff issues—that is, converting runoff series to present climate and underlying surface conditions for comparative analysis and investigating evolution trends of Taohe River runoff. Therefore, the Taohe River Basin was selected as the study area to conduct current runoff calculation research, providing fundamental support for comprehensive basin water resource utilization. This study uses long-term runoff data from Lijiacun and Hongqi representative hydrological stations as the basic dataset, employing the itemized investigation method and precipitation-runoff double mass relationship method to complete runoff reduction calculations. Based on these results, current runoff correction calculations were performed, and the variation characteristics of the current runoff were analyzed to provide scientific basis for comprehensive basin water resource management, scientific allocation, and environmental governance, while also offering reference for scientific evaluation and development management of river runoff under global warming and intensified human activities.

2 Data and Methods

2.1 Data Sources and Monitoring Stations Hydrological station measured precipitation and runoff data were obtained from the Gansu Provincial Bureau of Hydrology and Water Resources. Socio-economic water use data and water diversion project data were sourced from local water authorities. The Taohe River Basin in Gansu Province has seven main stream hydrological stations (Luqu, Xiagou, Minxian, Lijiacun, Hongqi) and eight tributary stations (Duoba, Yeliguan, Wangjiamo, Kangle, Yaodian, Lintao, Sanjiaji). Basic information for Lijiacun and Hongqi stations is provided in . Between the Lijiacun-Hongqi river section, there are main stream control station Hongqi and three major tributary control stations (Lintao, Kangle, Sanjiaji). The vast majority of water consumption in the Taohe River is concentrated in this area, primarily for agricultural irrigation in Lintao County and Guangtong River tributary areas. Major irrigation districts include Lintao Taohe Irrigation District, Dongyugou Irrigation District, Hongqi Irrigation District, Dongxiang Nanyang Irrigation District, Daban Irrigation District, Tangwang Irrigation District, Nalesi Irrigation District, Guoyuan Irrigation District, Kangle Fengtai Irrigation District, Hezheng Dalang Irrigation District, Heguang Irrigation District, Liangjiasi Reservoir, and Bujiazhuang Reservoir.

Areal rainfall calculations utilized data from 14 rainfall stations with good representativeness and long series in the Taohe River and adjacent basins, including Banyinpo, Qingping, and Yaodian. Missing or insufficient series at selected hydrological and rainfall stations were extended to 2016, with reasonable correlation analysis determining the final values.

2.2 Research Methods The runoff reduction method employed comprehensive data collection combined with typical survey analysis to perform annual (monthly) runoff reduction calculations for representative and control hydrological stations. Corresponding itemized reduction formulas and calculation processes were applied, combined with comprehensive balance analysis of upstream-downstream, main stream-tributary, and inter-regional relationships to complete accurate reduction calculations and rationality analysis.

The runoff correction method involved plotting double mass curves of precipitation and runoff to identify inflection points where the relationship changed significantly. These points served as the basis for dividing time periods, with consistency corrections applied to natural runoff in corresponding periods. On the basis of reduction calculations, current correction converted runoff generated under early underlying surface conditions to present conditions.

Linear trend fitting was used to describe runoff variation trends and calculate trend rates. The moving average method was employed to identify runoff variation patterns. The cumulative anomaly method diagnosed abrupt runoff changes. The Mann-Kendall test was used for mutation testing and trend analysis, applicable to hydrological and meteorological elements including temperature, precipitation, and runoff.

3 Runoff Reduction Calculation and Analysis

3.1 Runoff Reduction Calculation Statistical analysis of 1956–2016 measured runoff at Lijiacun and Hongqi stations yielded multi-year average measured runoff values of 39.52×10^{8} m^3 and 44.66×10^{8} m^3, respectively. Using the itemized reduction method, the multi-year average reduction water volumes were 0.17×10^{8} m^3 for Lijiacun and 1.45×10^{8} m^3 for Hongqi. Lijiacun's reduction volume comprised agricultural irrigation consumption, while Hongqi's included both agricultural irrigation and industrial water use, with a water consumption coefficient of 0.53 for Gansu Province farmland irrigation water utilization.

3.2 Runoff Consistency Analysis Double mass curves of areal average annual precipitation and natural annual runoff revealed a significant relationship change inflection point in 1990. Using this as the segmentation point, the series was divided into two periods, with consistency correction analysis applied to corresponding natural runoff (Fig. 2). After reduction, the multi-year average natural runoff values were 39.69×10^{8} m^3 and 46.11×10^{8} m^3 for Lijiacun and Hongqi, respectively. Comparison of measured and reduced natural runoff shows that natural runoff exceeds measured runoff at both stations, with both showing an initial increase followed by decrease, indicating that natural runoff has diminished with continuous human activity impacts.

3.3 Runoff Mutation Characteristics Mann-Kendall mutation testing of annual average natural runoff at Lijiacun and Hongqi stations (Fig. 4) shows that Lijiacun's runoff had positive UF values during 1956–1990, indicating an increasing trend, particularly significant in the 1960s–1970s when values exceeded the 0.05 significance critical line. Negative UF values in the 1990s–2010s indicate a decreasing trend exceeding the 0.05 significance level, showing significant decline during this period. The intersection point within the ±1.96 critical lines identifies 1990 as the mutation point. Hongqi station shows similar patterns with positive UF values during 1956–1990 and negative values during 1990–

2016, with 1990 identified as the mutation point, consistent with the consistency analysis inflection point.

4 Current Runoff Calculation and Analysis

Based on precipitation and runoff correction coefficient relationships, correction coefficients for different precipitation magnitudes at Lijiacun and Hongqi stations were determined for 1990–2016 as the basis for current runoff correction (Table 2). Using precipitation from the correction period and corresponding coefficients from the relationship curves, corrected runoff was obtained by multiplying natural annual runoff by the coefficients. Current runoff values are 31.76×10^{8} m^{3} for Lijiacun and 38.77×10^{8} m^{3} for Hongqi, representing reductions of 7.04×10^{8} m^{3} (20%) and 7.93×10^{8} m^{3} (15%), respectively, compared to reduced natural runoff (Fig. 5).

5 Variation Characteristics of Current Runoff

5.1 Runoff Variation Trends Following current calculation, the 1956–2016 multi-year average runoff values at Lijiacun and Hongqi stations are 31.76×10^{8} m^{3} and 38.77×10^{8} m^{3}, respectively. Lijiacun' s annual runoff ranges from 19.55×10^{8} m^{3} to 55.83×10^{8} m^{3} (ratio of 2.86), while Hongqi' s ranges from 24.40×10^{8} m^{3} to 72.20×10^{8} m^{3} (ratio of 2.96). Linear trend analysis shows Lijiacun' s runoff increasing slightly at 0.087×10^{8} m^{3} per decade (y = 0.0087x + 31.486), while Hongqi' s decreases slightly at 0.124×10^{8} m^{3} per decade (y = -0.0124x + 47.80). Five-year moving average curves reveal both stations exhibit slow fluctuating patterns with alternating rising and falling periods (Fig. 6).

5.2 Interannual Variation Characteristics Statistical analysis of current runoff yields characteristic values (Table 3). Lijiacun' s relatively low runoff periods were the 1990s–2000s (1.32×10^{8} m^{3} and 1.14×10^{8} m^{3} below the multi-year average), while the relatively high period was the 2010s (0.48×10^{8} m^{3} above average). Extremely dry years occurred in 1991, 2000, and 2002 (anomalies of -5.01×10^{8} m^{3}, -1.69×10^{8} m^{3}, and -5.36×10^{8} m^{3}), moderately wet years in 1967, 1975, and 2012, and normal years in 1962, 1970, and 2014. Hongqi station shows similar patterns with low periods in the 1990s–2000s and high periods in the 1960s–1970s and 2010s. Overall, Taohe River basin runoff was below the multi-year average in the 1990s-2000s and above average in the 1960s–1970s and 2010s, displaying distinct wet, normal, and dry interdecadal characteristics.

6 Discussion

Numerous irrigation districts and inter-basin water transfer projects have led to varying degrees of cultivated land expansion in the basin. Concurrently, ecological and engineering measures for soil and water conservation have altered regional vegetation coverage. These factors comprehensively changed underlying surface conditions and consequently modified runoff generation and concentration processes. Climate change impacts have also altered regional hydrology and meteorology, causing different runoff variation patterns. Additionally, varying irrigation areas and terrain conditions between Lijiacun and Hongqi stations contribute to their different post-correction trends.

While many scholars have studied runoff reduction, current runoff research remains limited, particularly for the Taohe River Basin where such studies are virtually nonexistent. This research distinguishes itself by moving beyond simple reduction to examine mutation characteristics, current runoff calculation, and post-correction trends and interannual variation. Future research should strengthen comprehensive analysis, cross-application of different methods, and enhanced analysis of climate change and human activity impacts on basin runoff.

7 Conclusions

From 1956 to 2016, the multi-year average measured runoff at Lijiacun and Hongqi stations in the Taohe River Basin were 39.52$\times10^{8}$ m^3 and 44.66$\times10^{8}$ m^3, respectively. After reduction calculation, the multi-year average natural runoff values were 39.69$\times10^{8}$ m^3 and 46.11$\times10^{8}$ m^3, with reduction water volumes of 0.17$\times10^{8}$ m^3 and 1.45$\times10^{8}$ m^3, primarily for agricultural irrigation. Mann-Kendall test results show consistent mutation trends at both stations, with mutation points in 1990. After current correction, runoff values are 31.76$\times10^{8}$ m^3 and 38.77$\times10^{8}$ m^3, representing reductions of 7.04$\times10^{8}$ m^3 and 7.93$\times10^{8}$ m^3, respectively. Lijiacun' s annual runoff increases slightly at 0.087$\times10^{8}$ m^3 per decade, while Hongqi' s decreases at 0.124$\times10^{8}$ m^3 per decade. Overall, Taohe River basin runoff was below the multi-year average in the 1990s–2000s and above average in the 1960s–1970s and 2010s, with distinct wet, normal, and dry periods. These results provide reference for regional water resource investigation, evaluation, and optimal layout.

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Note: Figure translations are in progress. See original paper for figures.