

## Spatiotemporal Variation Characteristics of Temperature in the Shule River Basin from 1951 to 2020 (Postprint)

**Authors:** Wang Shiwei, Sun Dongyuan, Zhou Min, Wang Yike, Wang Xiangbin, Ji Zong, Zhang Wenrui, Lan-Zhen Wu

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### Abstract

Based on measured temperature data from 1951 to 2020 at Dunhuang, Guazhou, and Yumen stations in the Shule River Basin, methods including linear trend analysis, cumulative anomaly, and Mann-Kendall test were employed to analyze the spatiotemporal variation characteristics of temperature at each station. The results indicate: (1) The average temperature at all stations in the Shule River Basin exhibited significant upward trends, with the trend rates ranked as follows: Dunhuang Station ( $0.244\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$ ,  $P < 0.05$ ) > Guazhou Station ( $0.209\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$ ,  $P < 0.05$ ) > Yumen Station ( $0.195\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$ ,  $P < 0.05$ ). (2) The seasonal average temperatures at Dunhuang and Yumen stations showed significant upward trends; at Guazhou Station, the average temperatures in spring, autumn, and winter showed significant upward trends, while the summer average temperature showed a non-significant upward trend. (3) The abrupt change years of average temperature at each station in the Shule River Basin were 1998, 1997, and 1995, respectively; the first principal periods were 58 a, 30 a, and 13 a, respectively. (4) The annual and seasonal average temperatures in the Shule River Basin gradually increased from east to west, while both the non-uniformity coefficient and concentration degree exhibited decreasing trends.

### Full Text

#### Temporal and Spatial Variation of Temperature in the Shule River Basin from 1951 to 2020

**WANG Shiwei, SUN Dongyuan, ZHOU Min, WANG Yike, WANG Xiangbin, JI Zonghu, ZHANG Wenrui, WU Lanzhen**

College of Water Conservancy and Hydropower Engineering, Gansu Agricultural University, Lanzhou 730070, Gansu, China

## Abstract

The linear tendency, cumulative anomaly, and Mann-Kendall test were used to analyze the temporal and spatial variation of temperature at Dunhuang, Guazhou, and Yumen stations in the Shule River Basin from 1951 to 2020. The results revealed that (1) all stations experienced a significant upward trend in average temperature, with tendency rates of  $0.244\text{ }^{\circ}\text{C}\text{ (10a)}^{-1}$  ( $P<0.05$ ) for Dunhuang station,  $0.209\text{ }^{\circ}\text{C}\text{ (10a)}^{-1}$  ( $P<0.05$ ) for Guazhou station, and  $0.195\text{ }^{\circ}\text{C}\text{ (10a)}^{-1}$  ( $P<0.05$ ) for Yumen station. (2) Dunhuang and Yumen stations exhibited a significant upward trend in average temperature across all seasons, while Guazhou station showed significant upward trends in spring, autumn, and winter, with a non-significant upward trend in summer. (3) The mutation years for average temperature at Dunhuang, Guazhou, and Yumen stations were 1998, 1997, and 1995, respectively, with the first main cycles being 58 a, 30 a, and 13 a, respectively. (4) Annual and seasonal average temperatures gradually increased from east to west in the Shule River Basin, with decreasing non-uniformity coefficients and concentration degrees also observed.

**Keywords:** temperature; temporal and spatial changes; M-K test; Morlet wavelet analysis; Shule River Basin

## Introduction

Since the 20th century, global climate warming has caused China to exhibit a significant warming and drying trend. Over the past 100 years, China's average surface temperature has increased by  $0.5\sim 0.8\text{ }^{\circ}\text{C}$ , with particularly pronounced changes in northwest arid and semi-arid regions. Climate change alters the temporal and spatial distribution of hydrological and meteorological factors within river basins, leading to the redistribution of water resources and seriously impacting water supply and demand, ecological environments, and socio-economic systems. The Shule River Basin, located in the Hexi inland region of Gansu Province, is one of the three major inland rivers in Gansu and a primary grain-producing area in Hexi. The basin's unique natural environment features limited biological diversity, and its ecological system is difficult to restore once damaged. Therefore, investigating the temporal and spatial variation characteristics of temperature in the basin is crucial for understanding temperature dynamics and promoting ecological construction.

In recent years, temperature change in the Shule River Basin has attracted widespread attention from scholars and government agencies. Research indicates that climate change, characterized by rising temperatures, has significantly affected water resources and the ecological environment in the basin, manifesting as increased vegetation water consumption, greater ecological carrying capacity and water demand, vegetation degradation, and changes in permafrost conditions. Basin precipitation and runoff have shown upward trends, while temperatures have risen significantly. Under future scenarios of continued warming, the Shule River Basin may face increasingly severe ecological threats. Previous

studies on temperature change in the basin have yielded meaningful results, but most have focused on the impacts of climate change rather than the temporal and spatial variation characteristics of temperature itself. Therefore, this study systematically analyzes the temporal and spatial variation of annual average temperature in the Shule River Basin over the past 70 years using measured temperature data from Dunhuang, Guazhou, and Yumen stations from 1951 to 2020, providing a scientific basis for ecological protection and coordinated development of society, economy, and water resources in the basin.

## 1. Study Area and Methods

### 1.1 Study Area Overview

The Shule River is the second largest inland river in the Hexi region of Gansu Province, located between 92°11'~98°30'E and 38°00'~42°48'N, covering a basin area of  $4.13 \times 10^4$  km<sup>2</sup>. The multi-year average temperature ranges from 6.98~9.82 °C, with annual precipitation of 40.2~57.5 mm and annual evaporation of 2577.4~2653.2 mm. The basin experiences extremely high evaporation and scarce precipitation, characterized by a continental arid climate that represents one of China's most arid regions.

### 1.2 Data Sources and Research Methods

Monthly and annual temperature data from Dunhuang (1951-2020), Guazhou (1951-2020), and Yumen (1951-2020) stations in the Shule River Basin were obtained from the Gansu Provincial Meteorological Bureau. Seasons were defined as spring (March-May), summer (June-August), autumn (September-November), and winter (December-February). The linear tendency method was employed to analyze annual and seasonal temperature trends, with P-values ( $P < 0.05$ ) used for significance testing. The cumulative anomaly method was applied to examine temperature variation processes, while the Mann-Kendall test identified abrupt temperature changes. Morlet wavelet analysis investigated temperature periodicity characteristics, and ArcGIS software analyzed spatial distribution patterns. [Figure 1: see original paper]

## 2. Results and Analysis

### 2.1 Interannual Temperature Variation Characteristics

The multi-year average temperature at Dunhuang station was 9.77 °C, showing a significant overall upward trend with a temperature increase of 1.708 °C over the study period. The moving average curve revealed a slow increase with multiple rising phases and fluctuating changes. The cumulative anomaly indicated two distinct periods of rise and fall at Dunhuang station. At Guazhou station, the multi-year average temperature was 9.08 °C, with a significant upward trend and a temperature increase of 1.463 °C. The moving average curve showed multiple rising phases with fluctuating changes, and the cumulative anomaly revealed two

periods of rise and fall. Yumen station had a multi-year average temperature of 7.30 °C, showing a significant upward trend with a temperature increase of 1.326 °C. The moving average curve demonstrated multiple rising phases, while the cumulative anomaly showed two periods of rise and fall. [Figure 2: see original paper]

## 2.2 Seasonal Temperature Variation Characteristics

Dunhuang station exhibited significant upward trends in seasonal average temperature across all seasons, with the largest tendency rate in spring at  $0.328\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), followed by winter at  $0.268\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), summer at  $0.233\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), and autumn at  $0.191\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ). Guazhou station showed significant upward trends in spring, autumn, and winter, with the largest tendency rate in winter at  $0.308\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), followed by spring at  $0.299\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ) and autumn at  $0.152\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ). Summer average temperature at Guazhou showed a non-significant upward trend of  $0.077\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P > 0.05$ ). Yumen station displayed significant upward trends in all seasons, with the largest tendency rate in spring at  $0.207\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), followed by winter at  $0.179\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), autumn at  $0.165\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), and summer at  $0.018\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ). [Figure 3: see original paper][Figure 4: see original paper][Figure 5: see original paper]

## 2.3 Temperature Abrupt Change Characteristics

Mann-Kendall mutation test curves revealed that Dunhuang station's average temperature showed an upward trend after 1970, with the UFk curve exceeding the 0.05 confidence level and even the 0.001 confidence level, indicating a highly significant upward trend. The UFk and UBk curves intersected primarily in 1998, with the intersection point within the critical lines of  $\pm \$1.96$ , indicating an abrupt temperature change in 1998. At Guazhou station, the UFk curve showed an upward trend after 1965, with the UFk curve exceeding the 0.05 confidence level, indicating a significant upward trend. The UFk and UBk curves intersected in 1997, with the intersection point within the critical lines of  $\pm \$1.96$ , indicating an abrupt change in 1997. Yumen station showed an upward trend after 1975, with the UFk curve exceeding the 0.05 confidence level, indicating a significant upward trend. The UFk and UBk curves intersected in 1995, with the intersection point within the critical lines of  $\pm \$1.96$ , indicating an abrupt change in 1995. [Figure 6: see original paper]

## 2.4 Temperature Periodicity Characteristics

Wavelet analysis revealed that Dunhuang station's average temperature exhibited five characteristic time scales: 3~8 a, 10~15 a, 25~30 a, 45~50 a, and 55~60 a. The wavelet variance diagram showed five distinct peaks, with the first main cycle at 58 a, second at 50 a, third at 25 a, fourth at 10 a, and fifth at 3 a. Guazhou station showed four characteristic time scales: 5~10 a, 10~15 a, 28~33

a, and 50~55 a, with four distinct peaks in the wavelet variance diagram. The first main cycle was 30 a, second 50 a, third 15 a, and fourth 5 a. Yumen station exhibited four characteristic time scales: 5~10 a, 10~15 a, 20~25 a, and 25~30 a, with four distinct peaks. The first main cycle was 13 a, second 25 a, third 15 a, and fourth 5 a. [Figure 7: see original paper]

## 2.5 Temperature Spatial Variation Characteristics

Annual and seasonal average temperatures in the Shule River Basin showed a gradual increase from east to west, following the pattern Yumen station < Guazhou station < Dunhuang station. Dunhuang and Guazhou stations are located in the central basin area at lower altitudes, with Dunhuang bordering the desert, experiencing drought and low rainfall, resulting in more high-temperature days. Yumen station is situated in the northern river valley at higher latitude and altitude, with consistently lower temperatures and more low-temperature days. [Figure 8: see original paper]

## 2.6 Analysis of Temperature Inhomogeneity and Concentration Changes

The annual average temperature non-uniformity coefficient for the Shule River Basin ranged from 0.45~0.69, with an average value of 0.57, maximum of 0.69 in 1968, and minimum of 0.45 in 2012, showing a weak decreasing trend with a tendency rate of  $-0.015 \cdot (10a)^{-1}$ . The concentration degree ranged from 0.72~1.08, with an average of 0.89, maximum of 1.08 in 1968, minimum of 0.72 in 2012, and a weak decreasing trend at  $-0.023 \cdot (10a)^{-1}$ . The decreasing trends in both non-uniformity coefficient and concentration degree indicate that temperature distribution in the basin is becoming more uniform. [Figure 9: see original paper]

## 3. Discussion

During the study period, annual and seasonal average temperatures in the Shule River Basin showed upward trends, consistent with previous research. The basin's average temperature increase rate of  $0.21 \text{ }^{\circ}\text{C} \cdot (10a)^{-1}$  aligns with findings from other scholars. Spring and winter warming rates were higher, contributing significantly to the annual temperature increase, while summer and autumn warming rates were lower, likely related to increased greenhouse gas emissions from human activities. The spatial pattern of increasing temperatures from east to west reflects the basin's topography, with higher latitudes and elevations in the east resulting in lower temperatures, while western areas approaching the desert have higher temperatures. The decreasing non-uniformity coefficient and concentration degree suggest temperature distribution is becoming more uniform, potentially increasing uncertainty in extreme temperature occurrences. Given the complexity of climate characteristics in northwest arid inland river basins, temperature changes are influenced by multiple factors, and future re-

search should strengthen investigations into temperature variation characteristics and predictions under environmental changes.

#### 4. Conclusions

Based on temperature data from Dunhuang, Guazhou, and Yumen stations in the Shule River Basin from 1951 to 2020, this study investigated temporal and spatial temperature variation characteristics, yielding the following conclusions:

1. All stations showed significant warming trends, with Dunhuang station at  $0.244\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), Guazhou station at  $0.209\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), and Yumen station at  $0.195\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$  ( $P < 0.05$ ), resulting in temperature increases of  $1.708\text{ }^{\circ}\text{C}$ ,  $1.463\text{ }^{\circ}\text{C}$ , and  $1.326\text{ }^{\circ}\text{C}$ , respectively.
2. Dunhuang and Yumen stations exhibited significant upward trends in seasonal temperatures across all seasons, while Guazhou station showed significant upward trends in spring, autumn, and winter, with a non-significant upward trend in summer.
3. Abrupt temperature changes occurred around 1997 at all stations, with mutation years of 1998, 1997, and 1995 for Dunhuang, Guazhou, and Yumen stations, respectively. The first main cycles were 58 a for Dunhuang, 30 a for Guazhou, and 13 a for Yumen, indicating significant differences in temperature periodicity characteristics across the basin.
4. Annual and seasonal average temperatures increased gradually from east to west, with higher temperatures concentrated at Dunhuang station. Both the non-uniformity coefficient and concentration degree showed decreasing trends, indicating more uniform temperature distribution.

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