Characteristics of Dry-Wet Climate Variation in Xinjiang and Its Influencing Factors: Postprint

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Abstract

Based on daily surface observation data from 56 meteorological stations in Xinjiang during 1961–2019, we analyzed the characteristics and causes of dry-wet changes in Xinjiang over the past 59 years. The main conclusions are as follows: (1) Xinjiang is undergoing a significant transition from dry to wet conditions. During 1961–2019, the regionally averaged Aridity Index (AI) increased at a rate of 0.01 · (10a)-1 ($P < 0.01$), with an abrupt shift occurring around 1987. The proportion of stations exhibiting a significant increasing trend was 57.1%. (2) Annual precipitation in Xinjiang increased significantly at a rate of 8.6 mm · (10a)-1 during 1961–2019, with the timing of its abrupt change consistent with that of AI. Annual reference evapotranspiration (ET0) exhibited a significant decreasing trend during 1961–2019, with a rate of -15.7 mm · (10a)-1. Notably, annual ET0 underwent a transition around 1990, decreasing continuously before 1990 and shifting to a fluctuating increase thereafter. (3) Variations in ET0 were primarily controlled by two climatic factors: wind speed and relative humidity. During 1961–2019, wind speed across the region generally decreased, and relative humidity at nearly half of the stations also decreased. The combined effect of these two factors resulted in a significant ET0 decrease at 50% of stations in Xinjiang. The transition in ET0 around 1990 was likewise induced by transitions in the trends of relative humidity and wind speed around 1990. Around 1990, relative humidity shifted from an increasing to a decreasing trend, while wind speed shifted from a decreasing to an increasing trend, collectively causing differences in ET0 trends between the two periods. These conclusions enhance our understanding of dry-wet changes and their underlying causes in Xinjiang and provide valuable reference for rational development and utilization of water resources in the region.

Full Text

Preamble

Based on daily ground observation data from 56 meteorological stations in Xinjiang from 1961 to 2019, this study analyzed the characteristics and causes of dry-wet changes in Xinjiang over the past 59 years. The main conclusions are as follows: (1) Xinjiang has experienced a significant transition from dry to wet conditions. During 1961-2019, the regional average aridity index (AI) increased at a rate of 0.01 · (10a)^-1 (P < 0.01), with an abrupt change detected around 1990. Stations showing a significant upward trend accounted for 57.1% of the total. (2) Annual precipitation in Xinjiang increased significantly at a rate of 8.6 mm · (10a)^-1, with the mutation time consistent with that of AI. Annual reference evapotranspiration (ET0) exhibited a significant decreasing trend at a rate of -15.7 mm · (10a)^-1. Notably, the ET0 trend shifted around 1990, decreasing continuously before 1990 and then transitioning to a fluctuating increase afterward. (3) ET0 variation was primarily controlled by wind speed and relative humidity. During 1961-2019, wind speed showed a decreasing trend across the region, while relative humidity decreased at nearly half of the stations. The combined effect of these two factors led to the significant ET0 decrease observed at approximately 50% of stations in Xinjiang. The shift in ET0 trends around 1990 was caused by the reversal of relative humidity and wind speed trends around that time.

Keywords: climate dry-wet changes; aridity index; evapotranspiration; driving factors; Xinjiang

Global warming has significantly intensified since the 20th century, profoundly affecting the global water cycle and altering the spatial-temporal distribution of precipitation and evapotranspiration at regional scales. According to regional water balance principles, changes in precipitation and evaporation influence regional water budgets and consequently affect water resource allocation patterns. Xinjiang, located in the interior of the Eurasian continent, is characterized by high precipitation variability, low total precipitation, large evapotranspiration, and an arid climate. Water resource scarcity and uneven spatial-temporal distribution have long constrained economic development in the region. With its fragile ecological environment, Xinjiang represents one of China's most sensitive areas to global climate change. Investigating climate dry-wet conditions in Xinjiang under climate change is crucial for ensuring regional ecological security and supporting sustainable economic development.

At the beginning of the 21st century, academician Shi Yafeng proposed the scientific hypothesis of "warming and humidification" in Northwest China's arid regions, challenging the previous understanding of "warming and drying" in the region. Subsequent studies using various drought indices have examined the observed facts, trends, causes, and future projections of this "warming and humidification" phenomenon. Xinjiang is considered the region with the most significant "warming and humidification" in Northwest China, though trends differ between northern and eastern parts of the arid region. Previous research has primarily focused on temperature and precipitation to explain "dry-wet" changes, while evapotranspiration, as a critical component of regional water budgets, has received less attention. Reference crop evapotranspiration (ET0) represents atmospheric evaporative capacity at specific locations and times, independent of crop characteristics and soil factors, serving as an important indicator for evaluating crop water requirements, climate dryness, water resource balance, and agricultural production potential. Since actual evapotranspiration data are difficult to obtain while ET0 is relatively easy to calculate, many studies have analyzed regional dry-wet conditions through ET0 changes. However, few studies have investigated how different climate factors influence ET0 changes in Xinjiang. With increasingly significant climate change in recent years, extending data sequences may reveal more pronounced change signals. This study utilizes long-term meteorological observations from 56 stations across Xinjiang from 1961-2019, employs the Food and Agriculture Organization (FAO) Penman-Monteith model to calculate ET0, uses the aridity index to quantify Xinjiang's dry-wet characteristics, and applies Mann-Kendall (M-K) test, sensitivity coefficient analysis, and contribution rate analysis to examine dry-wet change patterns and clarify how different climate factors contribute to ET0 changes.

1.1 Study Area Overview

Xinjiang is situated in the hinterland of the Eurasian continent. Geographically, it features the Kunlun Mountains, Tianshan Mountains, and Altai Mountains from south to north, with the Tarim Basin and Junggar Basin located between these mountain ranges. Its inland location far from oceans prevents moisture from penetrating deep into the region, creating an arid geographical environment dominated by temperate continental arid climate. The region has an average annual temperature of 7.6°C and average relative humidity of 57%. Total water resources are scarce at only 141.5 mm, with most stored as glacial ice.

1.2 Data Collection

This study collected daily observations of mean temperature, precipitation, relative humidity, wind speed, sunshine duration, and atmospheric pressure from 1961-2019 through the China Meteorological Administration's National Meteorological Information Center. The dataset underwent preliminary quality control by the National Meteorological Center. Following the Specifications for Surface Meteorological Observation, we performed secondary quality control to remove stations with excessive missing data. We selected stations with continuous observations of all six meteorological elements, resulting in 56 stations (Figure 1).

[Figure 1: see original paper]

1.3 Data Analysis

Among existing indices for evaluating regional drought and dry-wet conditions, the aridity index (AI) characterizes climate dryness by considering temperature effects on evapotranspiration and is suitable for representing long-term trends in climate state drought changes. The index is widely applied in dry-wet condition studies under climate change contexts. AI is calculated as:

$$AI = \frac{P}{ET_0}$$

where ET0 is annual reference crop evapotranspiration calculated using the Penman-Monteith formula, and P is annual precipitation. AI > 1 indicates that regional water income exceeds expenditure, with larger values indicating wetter conditions; AI < 1 indicates water income less than expenditure, with values closer to 0 indicating drier conditions.

We employed the Mann-Kendall test to assess temporal trend significance in data sequences, using P = 0.05 as the significance level. The Theil-Sen method quantified meteorological data trends, defining the slope as the climate tendency rate. To analyze how climate factor changes contributed to ET0 variation, we calculated contribution rates as the product of a climate factor's multi-year relative change rate and its sensitivity coefficient. The sensitivity coefficient indicator, originally proposed by McCuen and widely applied in evapotranspiration research, indicates how ET0 changes with a given climate factor. A positive contribution rate means the climate factor change leads to ET0 increase (positive contribution), while a negative rate indicates ET0 decrease (negative contribution).

2.1 Dry-Wet Characteristic Changes and Their Causes

Based on 1961-2019 observations from Xinjiang's 56 meteorological stations, the regional average aridity index ranged from 0.01 to 0.91. Among these stations, 6 could be classified as extreme arid zones (AI < 0.03), 42 as arid zones (0.03 ≤ AI < 0.2), 7 as semi-arid zones (0.2 ≤ AI < 0.5), and 1 as semi-humid zone (0.5 ≤ AI < 1). Statistical analysis revealed that extreme arid, arid, semi-arid, and semi-humid zones accounted for 1.84%, 75.4%, 20.5%, and 1.84% of Xinjiang's area, respectively.

During 1961-2019, Xinjiang showed a significant wetting trend, with 57.1% of stations exhibiting significant AI increases, primarily distributed in northwestern Xinjiang (Figure 2). The regional average AI displayed a fluctuating upward trend with a climate tendency rate of 0.01 • (10a)^-1 (P < 0.01), consistent with Shi Yafeng's conclusion that Xinjiang's climate began shifting around 1990.

[Figure 2: see original paper]

Since AI reflects regional water budget status, AI changes signify shifts in regional dry-wet types. Comparing the earliest (1961-1970) and latest (2010-2019) decades, the number of stations classified as extreme arid zones decreased by 4, arid zones decreased by 5, while semi-arid zones increased by 8 and semi-humid zones increased by 1, indicating that 14 stations experienced dry-wet zone transitions.

During 1961-2019, Xinjiang's annual precipitation increased significantly at 8.6 mm · (10a)^-1 ($P < 0.01$), with the mutation time consistent with AI. Stations showing significant precipitation increases accounted for 98.2%, mainly distributed on both sides of the Tianshan Mountains and the southern Altai Mountains. The regional mean annual precipitation tendency rate was 8.6 · (10a)^-1 ($P < 0.01$), aligning with Pu Zongchao's findings.

Conversely, annual ET0 showed a decreasing trend, with 50% of stations exhibiting significant declines. The regional average ET0 tendency rate was -15.7 mm · (10a)^-1 ($P < 0.01$). ET0 changes result from combined effects of water income (precipitation) and expenditure (evapotranspiration), though precipitation likely exerts greater influence than evapotranspiration. Chen Yaning's research indicates that precipitation changes dominate dry-wet variations in Northwest China, contributing over 60% of the total effect.

Notably, ET0 trends shifted around 1990. While annual precipitation continued rising after the 1990s, ET0 transitioned from decreasing to increasing. Based on these contrasting trends, we divided the study period into two phases: a wetter phase (1961-1990) and a drier phase (1991-2019), to explore differences in climate factor contributions to ET0 changes between periods.

2.2 Climate Change Causes of Reference Evapotranspiration Variation

The contribution rate represents how a climate factor's change affects ET0 variation. During 1961-2019, most Xinjiang stations showed decreasing ET0 trends. Figure 4 compares contribution rates and sensitivity coefficients of four climate factors based on 1961-2019 data. Different climate factors show substantial differences in magnitude. Temperature and sunshine duration have relatively small contribution rates, indicating minimal impact on ET0 trends. Relative humidity and wind speed exhibit larger contributions, suggesting more critical roles.

[Figure 4: see original paper]

Wind speed contributions ranged from -51.0% to 28.1%, with 94.6% of stations showing negative contributions. All stations had positive sensitivity coefficients for wind speed (Figure 4b), indicating ET0 changes correlate positively with wind speed—ET0 increases as wind speed increases. During 1961-2019, Xinjiang wind speed predominantly decreased, with significantly decreasing stations accounting for 73.2% and a regional tendency rate of -0.1 m · $s^{-1 \cdot (10a)}$-1 (P <

0.01). Therefore, decreasing wind speed contributed negatively to ET0 changes across most of Xinjiang.

Relative humidity contributions ranged from -25.1% to 20.5%, with a mean absolute value of 3.9%. Stations with positive and negative contributions were nearly equal, showing no clear spatial pattern. Relative humidity sensitivity coefficients ranged from -2.5 to -0.5, with all stations negative—ET0 increases correlate negatively with relative humidity increases. However, relative humidity contributions to ET0 change varied between positive and negative because contributions depend on both sensitivity coefficients and the factor's own trend. During 1961-2019, Xinjiang relative humidity trends were mixed (Figure 5), with increasing and decreasing stations each accounting for about 50% (Table 1). The regional average relative humidity tendency rate was 0.02% · (10a)^-1.

[Figure 5: see original paper]

When both relative humidity and wind speed contributed negatively, ET0 showed significant decreasing trends. When wind speed contributed negatively while relative humidity contributed positively with similar magnitude, ET0 trends were non-significant. When wind speed contributed negatively but with small magnitude or positively, while relative humidity contributed substantially positively, ET0 showed significant increasing trends. The combined effect of these two factors caused significant ET0 decreases at nearly half of Xinjiang's stations during 1961-2019.

2.3 Comparison Between Wetter and Drier Phases

Overall, the 1990 transition in ET0 trends resulted from shifts in relative humidity and wind speed trends (Figure 6). We further examined differences between the wetter (1961-1990) and drier (1991-2019) phases. During the wetter phase, both relative humidity and wind speed contributed negatively to ET0, with 71.4% and 94.6% of stations showing negative contributions, respectively. During the drier phase, contributions became predominantly positive, with positive contribution stations increasing to 57.1% and 55.4%, respectively.

[Figure 6: see original paper]

Relative humidity and wind speed sensitivity coefficients remained stable between phases, with similar median values and ranges. The difference lay in the climate factors' trend directions. Relative humidity increased during the wetter phase but shifted to a clear decreasing trend during the drier phase. Similarly, wind speed decreased during the wetter phase but increased during the drier phase. The high sensitivity coefficients of relative humidity and wind speed meant ET0 responded strongly to these factors, and their directional shifts caused the difference in ET0 trends between periods.

3 Conclusions

Based on daily observations from 56 meteorological stations during 1961-2019, this study analyzed Xinjiang's dry-wet characteristics, changes, and causes under climate change. The main conclusions are:

(1) Xinjiang experienced a significant transition from dry to wet conditions during 1961-2019. The aridity index (AI) increased at a rate of 0.01 · (10a)^-1 (P < 0.01), with 57.1% of stations showing significant upward trends. The number of stations classified as extreme arid and arid zones decreased by 4 and 5, respectively, while semi-arid and semi-humid zones increased by 8 and 1, respectively, indicating dry-wet zone transitions at 14 stations.

(2) AI changes resulted from combined variations in both water income (precipitation) and expenditure (evapotranspiration). During 1961-2019, Xinjiang's annual precipitation increased significantly at 8.6 mm · (10a)^-1, while annual ET0 decreased significantly at -15.7 mm · (10a)^-1. Nearly all stations (98.2%) showed significant precipitation increases, while 50% showed significant ET0 decreases. Although ET0 decreased overall during 1961-2019, the time series reveals a transition from decreasing to increasing around 1990.

(3) Relative humidity and wind speed contributed most to ET0 decreases. Wind speed showed a consistent decreasing trend across the region, contributing negatively at nearly all stations. Relative humidity decreased at about half of the stations. The combined effect of these two factors caused significant ET0 decreases at nearly 50% of stations. The ET0 trend shift from decreasing to increasing around 1990 resulted from trend reversals in relative humidity (from increasing to decreasing) and wind speed (from decreasing to increasing) around that time. These findings enhance understanding of Xinjiang's dry-wet changes and provide valuable insights for rational water resource development and utilization in the region.

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