Characteristics and Trends of Precipitation and Mean Temperature in the Xilin River Basin, 1961–2016: A Postprint

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Abstract

Using the cumulative anomaly method and non-parametric trend analysis methods for time series (the ITA method and ITA-CB method), this study analyzed precipitation and mean temperature data spanning the recent 56 years from 1961 to 2016 in the Xilin River Basin, a semi-arid grassland watershed in China, revealing the intra-annual, inter-annual, and inter-decadal variation characteristics of precipitation and mean temperature, and examining their seasonal and annual trends. The results indicate that from 1961 to 2016, precipitation in the Xilin River Basin was unevenly distributed, exhibiting pronounced seasonal characteristics within the year, with strong inter-annual fluctuations and marked differences. The average trend of annual precipitation was decreasing, with precipitation increasing in winter and spring while decreasing in summer and autumn. Notably, winter precipitation displayed a clear and stable increasing trend, greater in magnitude than that of spring. High-value zones of summer precipitation exhibited an enhanced increasing trend, whereas low-value zones showed an enhanced decreasing trend, thereby increasing the probability of extreme weather events. The average decreasing rate of autumn precipitation was relatively small, with both low-value and high-value zones showing increasing trends. Mean temperature demonstrated an overall pattern of initial decrease followed by increase, with 1987 serving as the inflection point, and exhibited a strong increasing trend on the inter-decadal scale. Results from the ITA and ITA-CB methods further revealed that the overall increasing trend of annual mean temperature in this region from 1961 to 2016 displayed a decelerating pattern. The increasing rate of mean temperature in spring and autumn exceeded that in summer and winter, and the temperature differences between seasons exhibited a decreasing trend.

Full Text

Change Characteristics and Trends of Precipitation and Average Temperature in the Xilinhe River Basin from 1961 to 2016

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Abstract

Atmospheric precipitation is considered an important hydrological resource in arid and semiarid areas because it can recharge runoff and affect the spatial and temporal distribution of regional water resources, which in turn influence the regional ecological environment. Temperature similarly affects many aspects of the regional water cycle, ecology, and vegetation. However, few studies have conducted trend analysis of precipitation and temperature in steppe watersheds. Therefore, the main purpose of this article is to determine the precipitation and temperature trends in a semiarid steppe watershed of north China—the Xilinhe River Basin located in Inner Mongolia.

Using the gridded monthly precipitation data from the China Meteorological Data Service Centre and the daily temperature data from the Xilinhot Meteorological Station, we first applied the cumulative anomaly method to briefly analyze the variation characteristics of precipitation and average temperature in the basin. Subsequently, the innovative trend analysis (ITA) and innovative trend analysis-change boxes (ITA-CB) methods were employed to detect precipitation and temperature trends in the study area.

The results showed that precipitation in the Xilinhe River Basin was unevenly distributed, with significant seasonal characteristics and strong interannual fluctuations. Annual precipitation was mainly concentrated in summer and autumn (accounting for approximately 83.1% of the total annual value). Precipitation was relatively low during 1961–1973, increased significantly during 1990–1998, decreased markedly during 1999–2011, and remained close to or above the average level after 2012. The basin's average temperature exhibited large differences in winter and small differences in summer, decreasing from 1961 to 1987 and increasing from 1988 to 2016.

The analysis further revealed that annual precipitation presented a decreasing trend during the recent 56 years (1961–2016). On a seasonal scale, precipitation showed increasing trends in winter and spring and decreasing trends in summer and autumn. In particular, winter precipitation rose significantly and steadily compared with spring precipitation. For summer precipitation, high-value areas showed a strengthening upward trend while low-value areas showed a strengthening downward trend, thus increasing the likelihood of extreme weather events. In autumn, the average rate of precipitation decline was small, with increasing trends observed in both low- and high-value areas. Although the increasing trends in winter and spring precipitation were significant, they had little effect on total annual precipitation change due to their limited quantities.

With 1987 serving as a turning point, the average temperature first decreased and then increased on an annual scale. The ITA and ITA-CB results further reflected that the overall increasing trend of the average annual temperature during the 56-year period was slowing down. The average temperature rise rate in spring and autumn was greater than that in summer and winter. During the coldest winter season, the average temperature rose at an accelerating rate, whereas during the hottest summer season, the temperature rise slowed down. Consequently, the temperature difference between seasons showed a decreasing trend.

Keywords: innovative trend analysis (ITA); innovative trend analysis-change boxes (ITA-CB); trend; Xilinhe River Basin; precipitation; average temperature

1. Introduction

Time series may exhibit increasing or decreasing trends, and numerous scholars have dedicated research to analyzing trends in hydrological and meteorological variables such as water quality, temperature, precipitation, runoff, and evapotranspiration. Early studies employed parametric methods like Kendall and Spearman Rho for trend analysis. These methods require not only sufficiently long sequences but also that the data satisfy normal distribution and independence assumptions—conditions that many time series fail to meet. To address autocorrelation issues, pre-whitening techniques were proposed, involving pre-whitening the time series before trend analysis. However, subsequent research demonstrated that such processing could eliminate important trend characteristics from the original series.

To overcome these limitations, Şen (2012) proposed an innovative trend analysis methodology (ITA) that is not constrained by requirements regarding serial correlation and offers intuitive interpretation. ITA has been widely applied to trend analysis of water quality, evaporation, precipitation, and temperature. Unlike conventional graphical observation methods that lack quantitative description, ITA enables more detailed and quantitative analysis of potential trends in time series. An improved version called innovative trend analysis-change boxes (ITA-CB) further divides data sequences into low-, medium-, and high-value zones for comprehensive trend analysis. This approach can detect the existence and magnitude of trends in each segment, calculate relative change rates, and determine whether trends are strengthening or weakening—capabilities that other methods lack.

Atmospheric precipitation is a crucial hydrological resource in arid and semiarid regions, recharging runoff and affecting the spatial-temporal distribution of water resources, which subsequently influences regional ecological environments. For semiarid steppe watersheds in northern China, precipitation significantly impacts forage production and grassland ecology. However, domestic research on precipitation trends has primarily focused on non-grassland areas, with few studies examining long-term precipitation trends in grassland regions. Li et al. analyzed precipitation trends in the Xilinhe River Basin at different time scales but did not account for serial autocorrelation. Song et al. conducted precipitation trend analysis and mutation tests using daily precipitation data from the Xilinhot Meteorological Station (1960–2014) at multiple temporal scales, finding that annual precipitation showed a non-significant decreasing trend, with no significant changes in spring, summer, or autumn, but a significant increasing trend in winter. Due to methodological limitations, these conclusions remained macroscopic analyses, leaving detailed questions unanswered—such as the specific characteristics of winter precipitation’ s significant upward trend, its rate of increase, and how trends vary across low, medium, and high-value segments.

Concurrently, temperature change has attracted scholarly attention amid global warming, as temperature affects regional water cycles, ecology, and vegetation. Inner Mongolia represents a climate-sensitive region and a typical temperate grassland area in China, yet research on climate impacts and temperature changes in grassland regions requires further investigation. In summary, studying precipitation and temperature changes in arid and semiarid grassland watersheds holds important practical significance. However, existing literature using methods such as Mann-Kendall and Sen’ s slope may produce inaccurate conclusions due to serial autocorrelation effects, and their results typically remain at the macroscopic level. ITA is not affected by serial autocorrelation, while ITA-CB can quantitatively analyze detailed trend characteristics at the micro level. Combining these complementary methods allows investigation of precipitation and temperature trends from both macroscopic and microscopic perspectives, providing a more comprehensive understanding of their changing patterns in the watershed.

2. Study Area and Data Sources

The Xilinhe River Basin, a typical representative of semiarid steppe watersheds, is located in the Xilingol Grassland of Inner Mongolia, with geographical coordinates between 115°25 -117°16 E and 43°24 -44°39 N, covering an area of 10,542 km^2. The basin experiences a mid-temperate semiarid continental monsoon climate characterized by large diurnal temperature variations, high evaporation, and low precipitation. The average annual precipitation is approximately 300 mm, concentrated mainly from June to September. Groundwater resources in the basin are extremely scarce. The watershed serves as an important base for animal husbandry development in Inner Mongolia and is critical for maintaining the stable natural ecological environment of Xilinhot City.

[Figure 1: see original paper] Location of the Xilinhe River Basin and meteorological stations

The precipitation data used in this study were obtained from the China Meteorological Data Service Centre (http://data.cma.cn/), specifically the 0.5°$×$0.5° gridded monthly precipitation dataset. Based on the latitude and longitude range of the Xilinhe River Basin, we selected 56 years of monthly precipitation data from 1961 to 2016 and organized them by quarter and year. Spring comprises March–May, summer June–August, autumn September–November, and winter December–February of the following year. Average temperature data were derived from daily mean values at the Xilinhot Meteorological Station for the same period.

3. Research Methods

The innovative trend analysis (ITA) methodology, proposed by Şen (2012), involves dividing the original data series into two equal parts, sorting each part in ascending order, and plotting the first part on the x-axis and the second part on the y-axis. If all scatter points fall above (or below) the 1:1 line, the series exhibits an increasing (or decreasing) trend. Furthermore, if the scatter distribution is approximately parallel to the 1:1 line, the trend is monotonic.

[Figure 2: see original paper] Diagram of trend classifications

The ITA-CB method first calculates the mean and standard deviation of the series, then divides the data into low-, medium-, and high-value zones based on the mean and standard deviation. ITA is subsequently applied to analyze trends within each zone, enabling more detailed investigation of internal variation patterns and facilitating comparison with overall trends. The change rate in ITA-CB is calculated as the percentage change after sorting, and box plots are generated to show the minimum, mean, and maximum change rates for each group. If the mean line in the box plot is closer to the minimum (or maximum) line, the trend change rate is considered negative (or positive), indicating a weakening (or strengthening) trend.

4. Results and Analysis

4.1 Variation Characteristics of Precipitation and Average Temperature

4.1.1 Annual Distribution Characteristics According to the data, the basin' s average annual precipitation is only 296.3 mm, with highly uneven distribution. Maximum precipitation occurs in July, minimum in December. Seasonally, annual precipitation concentrates in summer (June–August), accounting for 67.2% of the annual total, followed by autumn (September–November) at 27.8%. Winter precipitation is minimal, representing just 5.0% of the annual total. The basin' s average annual temperature is 2.6 °C, with the highest mean temperature in July and the lowest in January. Summer shows the smallest temperature variation (4.6 °C), while winter shows the largest (7.9 °C), indicating more dramatic temperature fluctuations in winter.

[Figure 3: see original paper] Annual distribution characteristics of precipitation and average temperature in the Xilinhe River Basin

4.1.2 Interannual Variation Characteristics The cumulative anomaly analysis reveals that the maximum annual precipitation was 491.6 mm (195.3 mm above the multi-year average), while the minimum was 129.9 mm (166.4 mm below the average). Overall, interannual precipitation variation was complex, with major turning points around 1973, 1990, 1998, and 2011. Precipitation was below average during 1961–1973, increased significantly during 1990–1998, decreased markedly during 1999–2011, and remained near or above average after 2012.

For temperature, the cumulative anomaly shows a different pattern. The maximum average temperature was 4.8 °C in 2007 (2.2 °C above the multi-year mean), while the minimum was 0.6 °C in 1967 (2.0 °C below the mean). Temperature remained above the multi-year average and showed an increasing trend after 1988, though precipitation during the same period was below average and decreasing.

[Figure 4: see original paper] Anomaly and cumulative anomaly of precipitation in the Xilinhe River Basin from 1961 to 2016
[Figure 5: see original paper] Anomaly and cumulative anomaly of temperature in the Xilinhe River Basin from 1961 to 2016

4.1.3 Interdecadal Variation Characteristics The interdecadal analysis shows that precipitation in the 1960s was above the multi-year average (331.7 mm), while the early 21st century (2000s) was notably dry (245.5 mm). Other decades remained close to the average with minor fluctuations. Average temperature increased monotonically from the 1960s to the 2000s, reaching its peak, then decreased slightly in recent years.

[Figure 6: see original paper] Interdecadal features of precipitation and temperature in the Xilinhe River Basin from 1961 to 2016

4.2 Trend Analysis Using ITA and ITA-CB

Applying ITA and ITA-CB to the data produced the results summarized in [Figure 7: see original paper] and [Figure 8: see original paper]. For spring precipitation, both low- and high-value zones showed increasing trends, with average change rates of 21.2% and 27.6%, respectively. The mean change rate lines in both zones approached their maximum values, indicating strengthening upward trends. However, the overall spring precipitation trend was not clearly reflected in the aggregate ITA analysis.

Summer precipitation exhibited a decreasing trend in low-value zones (average change rate: -19.5%) and an increasing trend in high-value zones (average change rate: 11.2%), with the medium-value zone showing a dominant decreasing trend. The box plots revealed that the mean change rate lines for both low- and high-value zones were close to their maximum lines, suggesting accelerating downward and upward trends, respectively. This pattern indicates an increasing likelihood of extreme weather events (droughts and floods).

Autumn precipitation showed increasing trends in both low- and high-value zones, though the low-value zone’ s upward rate was weakening while the high-value zone’ s rate strengthened. The medium-value zone displayed a decreasing trend with an average rate of -6.2%, resulting in a slight overall decline of -0.3% for autumn precipitation.

Winter precipitation demonstrated clear and stable increasing trends across all zones, with average change rates of 28.3% for low-value, 45.2% for medium-value, and 48.5% for high-value zones. All change rates were positive, and the upward trends showed signs of slowing.

Annual precipitation decreased in low- and medium-value zones (average change rates: -12.0% and -4.4%, respectively) while increasing in the high-value zone. The overall average change rate of -2.4% reflected a weakening decreasing trend.

For temperature, spring average temperature showed a clear increasing trend overall, with an average change rate of 54.5% that was slowing down. The low-value zone increased fastest but with a weakening trend, while the medium-value zone exhibited a strengthening upward trend (average change rate: 58.2%).

Summer average temperature displayed an overall increasing trend (average change rate: 24.0%) without significant acceleration or deceleration. Similar patterns occurred in medium- and high-value zones, while the low-value zone showed a slowing growth trend.

Autumn average temperature increased across all zones, with the low-value zone showing the fastest increase (average change rate: 76.8%), though all zones exhibited slowing upward trends.

Winter average temperature showed the most pronounced warming, with an overall average change rate of 72.5% that was accelerating. All zones displayed strengthening upward trends, with low-, medium-, and high-value zones showing average change rates of 110.0%, 71.4%, and 44.5%, respectively.

Annual average temperature increased significantly in the low-value zone (average change rate: 110.0%), with the overall trend showing a weakening upward pattern (average change rate: 48.5%). The slowing trend was most evident in the low-value zone and overall.

[Figure 7: see original paper] Precipitation trends in the Xilinhe River Basin obtained from ITA and ITA-CB from 1961 to 2016

[Figure 8: see original paper] Temperature trends in the Xilinhe River Basin obtained from ITA and ITA-CB from 1961 to 2016

5. Conclusions

This study utilized the 0.5°$×$0.5° gridded monthly precipitation dataset from the China Meteorological Data Service Centre and daily temperature data from the Xilinhot Meteorological Station to analyze variation characteristics and trends of precipitation and average temperature in the Xilinhe River Basin from 1961 to 2016.

Variation characteristics: 1. Precipitation distribution was extremely uneven both annually and interannually. Intra-annual distribution concentrated in summer and autumn (83.1% of annual total). Interannual distribution was complex and volatile, with precipitation continuously below average during the early 21st century, causing significant short-term declines. 2. Average temperature was lowest in January and highest in July, with large winter differences and small summer differences. Interannual characteristics showed a decreasing then increasing pattern with 1987 as the turning point. Interdecadal features showed monotonic increase from the 1960s to 2000s, followed by slight decreases.

Trend analysis: 1. Annual precipitation decreased in low- and medium-value zones while increasing in high-value zones, showing an overall decreasing trend. Seasonally, winter and spring precipitation increased while summer and autumn precipitation decreased, consistent with Li et al.' s findings but providing more detailed quantitative insights. 2. The overall increasing trend of annual average temperature was slowing down. Spring and autumn temperature rise rates (54.5% and 48.5%, respectively) exceeded those of summer and winter, with their upward trends clearly weakening. This pattern was particularly evident in low-value zones across seasons. Winter, the coldest season, showed accelerating warming, while summer, the warmest season, showed slowing warming. Consequently, seasonal temperature differences were decreasing year by year.

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