Trends and Spatial Variations of Precipitation in the Mongolian Plateau over the Past 54 Years: Postprint

Authors: Nayintai, Fuying Qin, Jia Gensuo, Yang Jie, Bao Yuhai, Qin Fuying

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Abstract

Over the past half-century, topics related to global climate have remained a focal point of scientific debate. Precipitation changes in the Mongolian Plateau, home to the world' s largest temperate grassland, constitute a global change issue and represent one of the most important driving factors of its fragile environmental changes. By utilizing monthly precipitation data from 136 meteorological stations on the Mongolian Plateau from 1961 to 2014, and employing Sen' s slope method, Mann-Kendall trend test, and spatial geostatistical methods, this study investigated the basic climatic characteristics and spatiotemporal variation patterns of precipitation elements in the region over the past 54 years. The results show that: (1) Annual precipitation on the Mongolian Plateau showed a decreasing trend over the past 54 years, with a trend of -2.30 mm · (10 a)-1 ($P > 0.05$). Overall, annual precipitation decreased significantly in the southeast and northwest, while increasing notably in the northeast and central-south. (2) Summer and autumn precipitation showed decreasing trends, with rates of -5.75 mm · (10 a)-1 and -0.42 mm · (10 a)-1 ($P > 0.05$), respectively; spring and winter precipitation showed significant increasing trends, with rates of 1.95 mm · (10 a)-1 and 0.50 mm · (10 a)-1 ($P < 0.05$). The years and cycles of positive and negative anomalies in seasonal precipitation differed. (3) The majority of stations showed increasing trends in spring and winter precipitation, accounting for 89.0% and 84.6% of all stations, respectively, mainly distributed in the northeastern and central-southern regions of the plateau; the majority of stations showed decreasing trends in summer and autumn precipitation, accounting for 80.1% and 57.4% of all stations, respectively, mainly distributed in the southeastern and northwestern regions of the plateau. This provides a scientific reference for accurately assessing climate change on the Mongolian Plateau and rationally proposing ecological and environmental decisions.

Full Text

5. Introduction

Global climate change has been a focal point of scientific debate for nearly half a century. Precipitation patterns across the Mongolian Plateau, which harbors the world' s largest temperate grassland, represent not only a critical global change issue but also a primary driver of environmental vulnerability in this fragile ecosystem. Previous studies have extensively documented climate change impacts on the plateau [9-11], with particular attention to vegetation dynamics and their climatic drivers [12-14].

Recent research indicates significant warming across the region, with temperature increases of approximately 0.85°C during 1940-2010 [7-8]. This warming trend has substantially altered the plateau's precipitation regime, affecting both ecological security and water resource availability [15-17]. Statistical analyses reveal that from 1969-2008, the plateau experienced a temperature rise of 2.07°C, with precipitation showing decreasing trends in some areas and increasing trends in others [7-8].

The seasonal redistribution of precipitation poses significant challenges for grassland ecosystems and agricultural production. Understanding spatiotemporal variations in precipitation is essential for assessing climate change impacts and developing adaptive management strategies. This study employs Mann-Kendall trend analysis and geostatistical methods to characterize precipitation changes across the Mongolian Plateau from 1961-2014, providing scientific basis for ecological conservation and regional planning.

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Corresponding author: QIN Fuying, Email: qinfuying@imnu.edu.cn

2. Data and Methods

2.1 Data Sources

Monthly precipitation data from 136 meteorological stations across the Mongolian Plateau were analyzed for the period 1961-2014. The dataset includes 60 years of continuous observations, covering four seasons: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February). Data quality control and homogeneity testing were performed following standard meteorological protocols [21-22].

2.2 Mann-Kendall Trend Test

The Mann-Kendall (M-K) non-parametric test was employed to detect monotonic trends in precipitation time series. This method is widely used in hydroclimatic trend detection due to its robustness against non-normal distributions and missing values [25-26].

The M-K statistic S is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i)$$

where sgn is the sign function:

$$\mathrm{sgn}(X_j - X_i) = \begin{cases} 1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases}$$

Here, $X_1, X_2, \ldots, X_n$ represent the precipitation time series, n is the number of observations, and X_j, X_i are data points at times j and i ($j > i$).

The standardized test statistic Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases}$$

where the variance of S is:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)}{18}$$

At significance level α, if $|Z| \geq Z_{1-\alpha/2}$, the null hypothesis of no trend is rejected, indicating a statistically significant trend at the α level.

1. Study Area

The Mongolian Plateau spans approximately 260×10^4 km² across northern China and Mongolia [23-24], representing a critical ecological transition zone. The plateau exhibits a pronounced elevation gradient, with most areas ranging from 1000–1500 m above sea level. The climate is characterized by a temperate continental regime with distinct seasonal patterns.

Precipitation distribution follows a strong seasonal cycle: spring (Qf: March-May) contributes 13.3% of annual precipitation, summer (Rf: June-August) contributes 68.0%, autumn (Sf: September-November) contributes 16.5%, and winter (Pf: December-February) contributes only 2.2%. The rainy season typically occurs from May to October, accounting for over 90% of annual precipitation.

The meteorological network comprises 136 stations, with 102 located within Inner Mongolia and 34 in Mongolia. Data completeness exceeds 99.9%, with missing values interpolated using inverse distance weighting [13]. Station distribution covers major ecological zones, including grassland, desert steppe, and forest-steppe transitions (Figure 1).

3. Results

3.1 Temporal Variations in Precipitation

3.1.1 Annual Trends Over the 54-year period (1961–2014), annual precipitation across the Mongolian Plateau averaged 305.6 mm, decreasing at a rate of -2.30 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$). The 1990s showed positive anomalies, while the 2000s exhibited negative anomalies. Significant decreasing trends were observed in the southeastern and northwestern regions, while increasing trends occurred in the northeastern and central-southern areas.

3.1.2 Seasonal Characteristics Seasonal precipitation totals were: - Spring (Qf): 40.6 mm (13.3% of annual) - Summer (Rf): 207.9 mm (68.0% of annual) - Autumn (Sf): 50.4 mm (16.5% of annual) - Winter (Pf): 6.8 mm (2.2% of annual)

Summer precipitation showed the highest interannual variability, with a decreasing trend of -5.75 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$). Autumn precipitation decreased at -0.42 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$). In contrast, spring and winter precipitation showed significant increasing trends of $+1.95$ mm $\cdot$ $(10a)^{-1}$ ($P < 0.05$) and $+0.50$ mm $\cdot$ $(10a)^{-1}$ ($P < 0.05$), respectively.

3.2 Spatial Patterns of Change

3.2.1 Seasonal Trend Distribution Spatial analysis revealed distinct regional patterns: - **Spring:** 89.0% of stations showed increasing trends, primarily in the northeastern and central-southern plateau - **Summer:** 80.1% of stations showed decreasing trends, concentrated in the southeastern and northwestern regions - **Autumn:** 57.4% of stations showed decreasing trends - **Winter:** 84.6% of stations showed increasing trends

The fraction of summer precipitation declined significantly, while non-summer precipitation contributions increased, indicating a seasonal redistribution of rainfall across the plateau.

5. Conclusions

(1) Over the past 54 years, annual precipitation across the Mongolian Plateau decreased at -2.30 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$), with the 1990s showing wet anomalies and the 2000s showing dry anomalies. Significant decreasing trends dominated the southeastern and northwestern regions, while increasing trends characterized the northeastern and central-southern areas.

(2) Seasonal precipitation distribution was highly asymmetric: summer contributed 68.0% of annual totals (207.9 mm), while winter contributed only 2.2% (6.8 mm). Spring and autumn accounted for 13.3% (40.6 mm) and 16.5% (50.4 mm), respectively.

(3) Summer and autumn precipitation showed decreasing trends of -5.75 mm$\cdot$(10a)$^{-1}$ and -0.42 mm$\cdot$(10a)$^{-1}$ (both $P > 0.05$), while spring and winter precipitation increased significantly at $+1.95$ mm$\cdot$(10a)$^{-1}$ and $+0.50$ mm$\cdot$(10a)$^{-1}$ (both $P < 0.05$).

(4) The majority of stations (89.0% and 84.6%) exhibited increasing trends for spring and winter precipitation, mainly in the northeastern and central-southern plateau. Conversely, decreasing summer and autumn trends occurred at 80.1% and 57.4% of stations, primarily in the southeastern and northwestern regions.

The observed decline in summer precipitation, coupled with significant warming, will likely intensify evapotranspiration rates, potentially causing water shortages, drought conditions, and reduced vegetation productivity across the Mongolian Plateau.

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Abstract: The topic of global climate has been the focus of scientific debate for nearly half a century. Precipitation change of Mongolian Plateau, where distributes the largest temperate grassland in the world, is not only a global change issue, but also one of the main driving factors of its fragile environment change. Climatic characteristics of precipitation and its spatial and temporal variations were analyzed with Sen' s slope, Mann-Kendall trend test and geostatistical method based on the monthly precipitation data of 136 weather stations across the Mongolian Plateau during 1961—2014. The results show as follows: (1) Plateau averaged multi-year mean annual precipitation was 305.6 mm with spatial distribution gradually decreasing from the northern, eastern and southeastern parts of the Plateau to the central regions. Annual precipitation showed a decreasing trend at the rate of -2.30 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$) over the Mongolian Plateau in recent 54 years with the obvious positive anomalies in the 1990s and negative ones in the 2000s of 21st century. On the whole, significant decreasing trends of annual precipitation were observed in the southeastern and northwestern region, while significant increasing trends were found in the northeastern and central and southern regions. (2) Seasonal mean precipitation is 40.6 mm, 207.9 mm, 50.4 mm and 6.8 mm in spring, summer, autumn and winter, accounting for 13.3%, 68.0%, 16.5% and 2.2% of the annual precipitation, respectively. In inter-annual variability, precipitation in summer and autumn showed a decreasing trend at the rate of -5.75 mm $\cdot$ $(10a)^{-1}$ and -0.42 mm $\cdot$ $(10a)^{-1}$ ($P > 0.05$) over the period of 1961—2014, while precipitation in spring and winter showed a significant increasing trend at the rate of 1.95 mm $\cdot$ $(10a)^{-1}$ and 0.50 mm $\cdot$ $(10a)^{-1}$ ($P < 0.05$), respectively. The years with positive or negative anomaly and periodic changes are quite different for the seasonal precipitation. (3) A majority of stations showed increasing trend for spring and winter precipitation, which accounting for 89.0% and 84.6% of all stations, respectively, and mainly distributed in the northeastern and central southern part of the Mongolian Plateau. While a large number of stations displayed decreasing trend for summer and autumn precipitation, which accounting for 80.1% and 57.4% of all stations, respectively, and mainly located in the southeast and northwest parts of this Plateau. This paper found opposite trends in the fraction of summer precipitation, with significant declines, while the contribution of non-summer (spring, autumn and winter) precipitation increased, which implied a seasonal reallocation of precipitation in the study area. A decline of summer precipitation together with a strong temperature increase will increase evaporation rates, which will likely cause water resources shortages, drought, and declines in vegetation productivity. This paper could provide scientific reference for accurate assessment of climate change and reasonable decision-making of ecological environment across the Mongolian Plateau.

Keywords: Mongolian Plateau; precipitation; change trends; seasonal variation; regional differentiation

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