Variation Characteristics of Summer Precipitation in the Arid Region of Northwest China from 1961 to 2022 (Postprint)

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Abstract

Based on daily precipitation data from 102 meteorological stations in the arid region of Northwest China from June to August during 1961–2022, this study analyzes the spatiotemporal variation characteristics of extreme and non-extreme precipitation and the differences in changes of the two precipitation types across different subregions in the arid region of Northwest China. The results show that: (1) Summer precipitation in the arid region of Northwest China exhibits an overall increasing trend, particularly pronounced in the Ili River Valley and western Tarim Basin, where its average contribution to annual total precipitation exceeds 40%. (2) The contribution of summer extreme precipitation to total precipitation in the arid region of Northwest China is approximately 45%, showing an overall increasing trend, especially significant in the western Tarim Basin, Hexi-Alashan, and northern Xinjiang. (3) At most meteorological stations in the arid region of Northwest China, summer extreme precipitation amount, extreme precipitation days, and extreme precipitation intensity all show increasing/enhancing trends; at most stations, non-extreme precipitation days decrease significantly, while non-extreme precipitation intensity increases notably. In the western Tarim Basin, the increase in summer precipitation is jointly contributed by increases in extreme and non-extreme precipitation, accounting for 61% and 39% of the total precipitation increase, respectively; in other regions, the increase in summer precipitation is mainly contributed by the increase in extreme precipitation. These findings enhance our understanding of the climatic change characteristics of the two precipitation types in summer over the arid region of Northwest China.

Full Text

Variation Characteristics of Summer Precipitation in the Arid Region of Northwest China from 1961 to 2022

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Abstract

Based on daily precipitation data from 102 meteorological stations in the arid region of northwest China during June–August from 1961 to 2022, this study analyzes the spatiotemporal variation characteristics of extreme and non-extreme precipitation and compares differences in precipitation changes across various sub-regions. The results reveal three key findings. First, summer precipitation in the arid region of northwest China exhibited an overall increasing trend, particularly pronounced in the Ili River Valley and western Tarim Basin, where the average contribution to annual total precipitation exceeded 40%. Second, summer extreme precipitation accounted for approximately 45% of total precipitation and showed an increasing trend, especially in the western Tarim Basin, Hexi-Alashan, and northern Xinjiang. Third, most meteorological stations recorded increasing trends in extreme precipitation amount, extreme precipitation days, and extreme precipitation intensity. However, the number of non-extreme precipitation days decreased significantly at most stations, while non-extreme precipitation intensity increased markedly. In the western Tarim Basin, the increase in summer precipitation resulted from combined contributions from both extreme and non-extreme precipitation, accounting for 61% and 39% of the total increase, respectively. In other regions, the rise in summer precipitation was predominantly driven by increases in extreme precipitation. These findings enhance understanding of climate change characteristics of different precipitation types in the arid region of northwest China during summer.

Keywords: extreme precipitation; non-extreme precipitation; spatiotemporal characteristics; regional differences; arid region of northwest China

1. Introduction

Global warming has led to non-uniform changes in precipitation and temperature, resulting in two primary terrestrial climate regimes: warm-dry and warm-wet. The latest IPCC report indicates that global temperatures will continue rising, bringing more extreme weather and climate events. Arid regions, characterized by scarce precipitation and fragile ecosystems, exhibit particularly sensitive responses to climate change. While most global land arid regions are

becoming drier, northwest China shows a clear warming-wetting trend with significant precipitation increases. Previous research demonstrates that since the 1980s, the area and intensity of wetting in northwest China have expanded substantially, with most meteorological stations showing significant increases in annual precipitation, especially after the 1990s. Extreme precipitation events have intensified, increasing the risk of hydrological and geological disasters in the region.

Extreme precipitation in northwest China' s arid region exhibits distinct spatial patterns, with more events in mountainous areas than in plains. The Tianshan Mountains and northern Xinjiang show significant increasing trends in extreme precipitation, with heavy rainfall days increasing most notably during flood seasons. Southern Xinjiang, central Tianshan, and northern Junggar Basin exhibit increasing summer extreme precipitation intensity. Studies indicate that extreme precipitation probability is higher in northern Xinjiang, with extreme precipitation amounts decreasing from mountains to basins. Despite these advances, two key questions remain unanswered: (1) Do extreme and non-extreme precipitation show consistent spatiotemporal variation characteristics? (2) Given the pronounced regional characteristics of precipitation in northwest China' s arid region, what specific differences exist among sub-regions? To address these questions, this study employs daily summer precipitation data from 102 meteorological stations from 1961 to 2022 to analyze spatiotemporal variation characteristics of summer precipitation, reveal differences between extreme and non-extreme precipitation changes, and compare precipitation variation characteristics across sub-regions.

2. Data and Methods

2.1 Study Area

The arid region of northwest China (73°–107°E, 35°–50°N) constitutes a major component of Central Asia' s arid zone, covering approximately 24.5% of China' s territory. The region includes all of Xinjiang, the Hexi Corridor in Gansu, the Qilian Mountains in Qinghai, and the Alashan Plateau in Inner Mongolia [Figure 1: see original paper]. With average annual precipitation below 200 mm, it represents one of the driest areas at similar latitudes globally, featuring a typical continental arid climate and fragile ecosystems that have exhibited a warming-wetting trend in recent decades.

2.2 Data Sources

Daily precipitation data for June–August from 1961 to 2022 at 102 meteorological stations in northwest China' s arid region were obtained from the National Meteorological Information Center [Figure 1: see original paper]. The data underwent quality control processing, with stations excluded if they had more than 10% missing observations in any given year during the study period.

2.3 Methods

The 95th percentile threshold method was used to identify extreme precipitation events. For each station, all daily precipitation amounts $ $0.1 mm during the study period were sorted in ascending order, with the 95th percentile value defined as the extreme precipitation threshold. A day with precipitation exceeding this threshold was classified as an extreme precipitation event; otherwise, it was classified as non-extreme. Indices for extreme and non-extreme precipitation included precipitation amount, days, intensity, and contribution to total precipitation .

To reveal regional precipitation characteristics, K-means clustering was applied to summer precipitation days ($ $0.1 mm), dividing the arid region into five subregions: northern Xinjiang, western Tarim Basin, Tianshan Mountains, Hexi-Alashan, and northeastern Tarim Basin-eastern Xinjiang [Figure 1: see original paper].

3. Results and Analysis

3.1 Basic Characteristics of Summer Precipitation

Summer precipitation accounts for the largest proportion of annual total precipitation in northwest China' s arid region, exceeding 40% on average. The contribution reaches 50–60% in the Tianshan Mountains and northern Xinjiang, 40–50% in the western Tarim Basin, and over 60% in the Alashan region and eastern Xinjiang [Figure 2: see original paper]. The spatial distribution shows high-value areas in the Tianshan and Qilian Mountains with average summer precipitation of 150–200 mm, while the western Tarim Basin receives less than 100 mm and eastern areas less than 50 mm [Figure 3: see original paper].

Significant increasing trends in summer precipitation occurred at 83.33% of stations, with 32.35% showing statistically significant increases concentrated in the western Tarim Basin and Ili River Valley [Figure 3: see original paper]. The regional average summer precipitation was 68.01 mm, with a significant increasing trend of 4.40 $\text{mm} \cdot (10\text{a})^{-1}$. Precipitation days averaged 20.37 days, with 73.53% of stations showing increasing trends and 23.52% significant increases, primarily in the western Tarim Basin [Figure 3: see original paper].

3.2 Spatiotemporal Characteristics of Extreme Precipitation

The spatial pattern of extreme precipitation closely matches that of total precipitation, with high values in the Tianshan and Qilian Mountains averaging 40–60 mm, and low values in the Tarim Basin and eastern Xinjiang below 30 mm [Figure 4: see original paper]. Regional average extreme precipitation was 31.13 mm, showing a significant increasing trend of 2.0 $\text{mm} \cdot (10\text{a})^{-1}$, with 81.37% of stations increasing and 31.37% significantly increasing, particularly in the western Tarim Basin and Ili River Valley [Figure 4: see original paper].

Extreme precipitation days averaged 4.02 days, with a significant increasing trend of 0.12 days·(10a)$^{-1}$. Extreme precipitation intensity averaged 11.52 mm·d^{-1}, increasing significantly by 0.34 mm·d^{-1}·(10a)$^{-1}$, with 73.53% of stations showing increasing intensity and 21.57% significantly increasing, concentrated in the western Tarim Basin [Figure 4: see original paper]. The contribution of extreme precipitation to total precipitation exceeded 40% across most regions, reaching over 50% in parts of the Tarim Basin [Figure 5: see original paper]. The regional average contribution was 45.8%, increasing significantly at 1.30%·(10a)$^{-1}$, with 78.43% of stations showing increasing trends, particularly in the western Tarim Basin and Ili River Valley [Figure 5: see original paper].

3.3 Spatiotemporal Characteristics of Non-Extreme Precipitation

Non-extreme precipitation showed high values in the Tianshan and Qilian Mountains (80–120 mm) and low values in the Tarim Basin and eastern Xinjiang (below 30 mm) [Figure 6: see original paper]. The regional average was 36.88 mm, with 62.75% of stations showing increasing trends and 15.68% significantly increasing. Non-extreme precipitation days averaged 18.35 days, with 78.43% of stations decreasing significantly, particularly in the Tianshan and Qilian Mountains [Figure 6: see original paper]. Non-extreme precipitation intensity averaged 2.02 mm·d^{-1}, showing a significant increasing trend of 0.11 mm·d^{-1}·(10a)$^{-1}$, with 78.43% of stations increasing and 11.76% significantly increasing [Figure 6: see original paper].

3.4 Comparison of Extreme and Non-Extreme Precipitation Changes Across Sub-Regions

All five sub-regions showed increasing trends in both total and extreme precipitation, while non-extreme precipitation decreased slightly in the Tianshan Mountains and Hexi-Alashan but increased elsewhere [Figure 7: see original paper].

Northern Xinjiang showed average summer precipitation of 111.50 mm, increasing at 4.40 mm·(10a)$^{-1}$, with extreme precipitation (30.49 mm) increasing at 1.70 mm·(10a)$^{-1}$ and non-extreme precipitation decreasing slightly. Extreme precipitation days (4.02) increased while non-extreme days (18.35) decreased. Extreme precipitation intensity (12.82 mm·d^{-1}) increased significantly, with the rise in extreme precipitation driven primarily by increased frequency [FIGURE:8–9].

Western Tarim Basin exhibited average summer precipitation of 82.24 mm, increasing significantly at 4.80 mm·(10a)$^{-1}$. Both extreme precipitation (30.49 mm) and non-extreme precipitation (51.75 mm) increased significantly, contributing 61% and 39% to the total increase, respectively. Extreme precipitation days (1.33) and non-extreme days (12.07) both increased, as did both precipitation intensities (extreme: 12.95 mm·d^{-1}; non-extreme: 1.45 mm·d^{-1}) [FIGURE:8–9].

Tianshan Mountains had the highest average summer precipitation at 193.74 mm, increasing at 1.80 mm $\cdot$ $(10a)^{-1}$. Extreme precipitation (46.45 mm) increased while non-extreme precipitation (147.29 mm) decreased slightly. Extreme precipitation days (4.02) increased as non-extreme days (38.06) decreased, with both intensities increasing [FIGURE:8-9].

Hexi-Alashan showed average summer precipitation of 84.51 mm, increasing at 1.60 mm $\cdot$ $(10a)^{-1}$. Extreme precipitation (20.04 mm) increased while non-extreme precipitation (64.47 mm) decreased slightly. Extreme precipitation days (2.23) increased as non-extreme days (20.26) decreased, with both intensities increasing [FIGURE:8-9].

Northeastern Tarim Basin-Eastern Xinjiang, the driest sub-region, averaged 34.99 mm summer precipitation, increasing at 1.90 mm $\cdot$ $(10a)^{-1}$. Extreme precipitation (17.39 mm) increased while non-extreme precipitation (17.60 mm) decreased slightly. Extreme precipitation days (1.34) increased while non-extreme days (12.16) decreased, with extreme intensity decreasing slightly but non-extreme intensity increasing [FIGURE:8-9].

4. Conclusions

This study reveals four major findings about summer precipitation in northwest China' s arid region from 1961 to 2022. First, the region averaged 68.01 mm summer precipitation over 20.37 days, contributing over 40% to annual totals on average. The contribution exceeded 50% in the Alashan and eastern Xinjiang areas. Summer precipitation increased at 83.33% of stations, with significant increases in the western Tarim Basin and Ili River Valley, while precipitation days increased at 73.53% of stations.

Second, average extreme precipitation was 31.13 mm, increasing significantly at 2.0 mm $\cdot$ $(10a)^{-1}$, with 81.37% of stations showing increases and significant rises in the western Tarim Basin and Ili River Valley. Since the late 1990s, extreme precipitation has been consistently above average, increasing hydrological and geological disaster risks. Extreme precipitation contributed 45.8% to total precipitation on average, with its contribution increasing at 78.43% of stations, particularly in the western Tarim Basin.

Third, most stations showed increasing non-extreme precipitation but decreasing non-extreme precipitation days, indicating that increased intensity drove the rise in non-extreme precipitation amounts. Non-extreme precipitation intensity increased significantly across the region.

Fourth, all sub-regions exhibited increasing total and extreme precipitation. In the western Tarim Basin, both extreme and non-extreme precipitation contributed to the total increase (61% and 39%, respectively), while other regions were dominated by extreme precipitation increases. Extreme precipitation increases resulted from combined contributions of more frequent events and greater intensity, whereas non-extreme precipitation increases (except in

the western Tarim Basin) stemmed primarily from intensity enhancement.

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